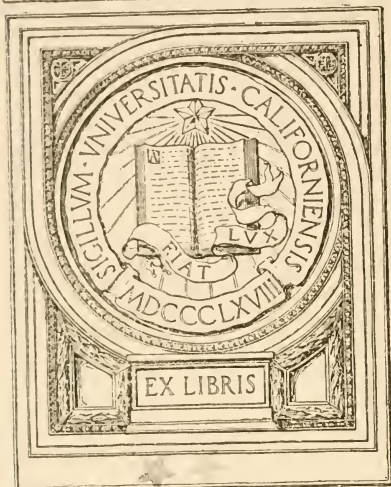


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Researches on Egyptian Bilharziosis

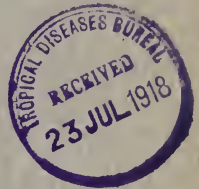
(A REPORT TO THE WAR OFFICE ON THE RESULTS OF THE
BILHARZIA MISSION IN EGYPT, 1915)

BY

R. T. LEIPER, M.D., D.Sc.

Reader in Helminthology in the University of London; First Wandsworth Scholar and Helminthologist to the London School of Tropical Medicine. During the Inquiry a Consultant Parasitologist and Temporary Lieut.-Colonel R.A.M.C.

[Reprinted from "The Journal of the Royal Army Medical Corps," Vol. XXV, pp. 1, 147, 253, 1915; Vol. XXVII, p. 171, 1916; Vol. XXX, p. 235, 1918]



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PREFACE.

As each of the various sections of the Report on the results of my mission to Egypt were published by the War Office in the *Journal of the Royal Army Medical Corps* a few reprints were made on a consecutive pagination. Permission has been obtained to bind these together, under a short title, for the greater convenience of those who may wish to consult the Report as a whole.

The sections here reprinted appeared under the following dates:—

Part I (pp. 1-48).—Transmission. (*Journal of the Royal Army Medical Corps*, July, 1915.)

Part II (pp. 49-84).—Prevention and Eradication. (*Journal of the Royal Army Medical Corps*, August, 1915.)

Part III (pp. 85-94).—Development. (*Journal of the Royal Army Medical Corps*, September, 1915.)

Part IV (pp. 95-112).—Egyptian Mollusca. (*Journal of the Royal Army Medical Corps*, August, 1916.)

Part V (pp. 113-132).—Adults and Ova. (*Journal of the Royal Army Medical Corps*, March, 1918.)

Part VI (pp. 133-140).—Bearing of Previous Work on *B. japonica*, and Concluding Remarks. (*Journal of the Royal Army Medical Corps*, March, 1918.)

Appendix (pp. i-xxvii).—Bibliography of Bilharziosis. (*Journal of the Royal Army Medical Corps*, July, August and September, 1915.)

In dealing with the prevention of the disease in the Army, I have taken occasion to bring under notice certain features in the bionomics of the intermediary hosts, and in the irrigation methods which give promise of effective means by which the Egyptian and Soudan Governments can, without vast special expenditure, bring about a great reduction in the infectivity of already infested districts, and the total exclusion of the essential carriers of the disease from newly reclaimed land. The almost hopeless task of endeavouring to control the disease by changing the ingrained habits and traditional practices of the people may thus be avoided.

To the various authorities in Egypt, to my colleagues, Captain J. G. Thomson and Dr. R. P. Cockin, and to Sergeant W. McDonald, R.A.M.C., who aided the investigations there, I have expressed my deep indebtedness in the body of the Report.

I wish to acknowledge here most gratefully the warm encouragement received during the inquiry from Colonel W. H. Horrocks, C.B., who found time amid heavy burdens to write emphasizing the practical objectives to

Preface

be kept strictly in view; and from the Medical Research Committee, who not only gave more than ample financial credit for the field expenses, and to illustrate this Report, but also maintained, through Sir W. M. Fletcher, F.R.S., a gracious interest in the progress of the work.

Thanks are due to Sir David Bruce for privileges enjoyed under his command at Millbank, and to the officials of the Zoological Society of London, especially to Dr. Chalmers Mitchell and Mr. R. I. Pocock, F.R.S., for supervising the supply by dealers of properly identified *Cercocobus fuliginosus*, which were the mainstay of the experimental work.

I have also to express my sense of indebtedness to the Committee of the London School of Tropical Medicine for most generously enabling me to continue under Army auspices a series of investigations which they had initiated during 1913, and which they would probably have supported alone to a successful conclusion if more peaceful times had prevailed.

London School of Tropical Medicine,
Albert Dock, London, E.,

R. T. LEIPER.

March 12th, 1918.

ERRATA.

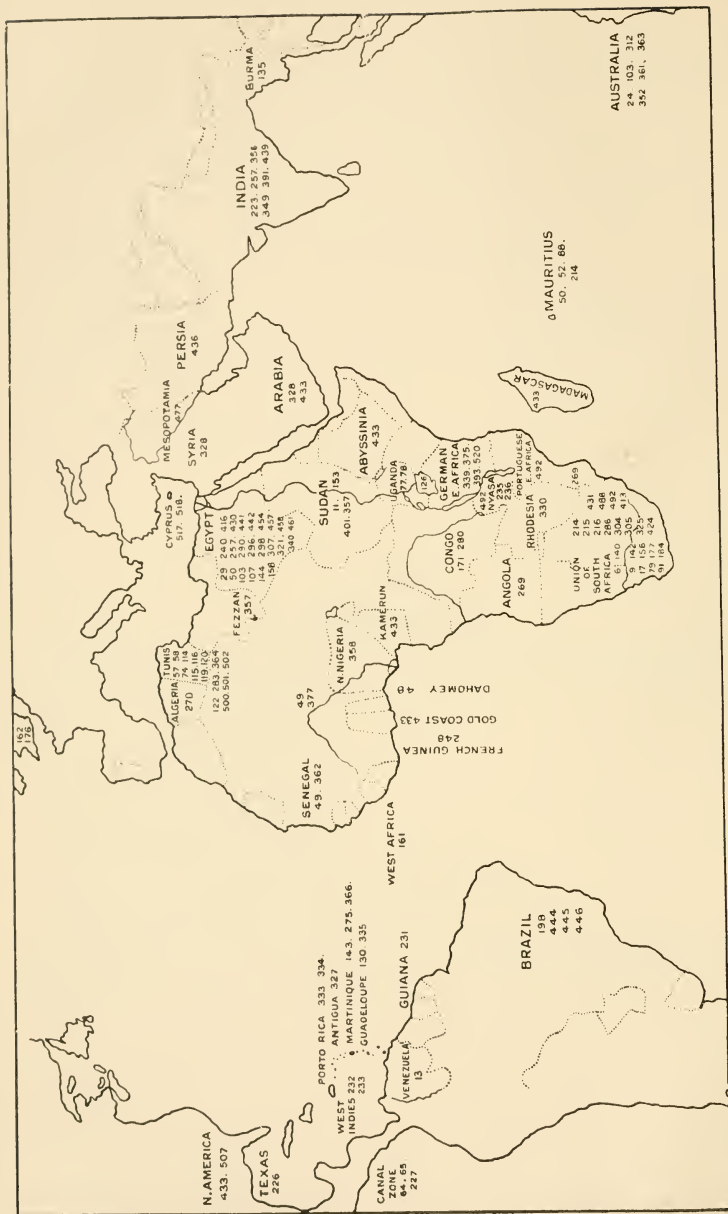
I am indebted to Dr. Shipley, Master of Christ's College, for drawing attention to a number of errors in the text, and particularly to the following, which escaped correction in the proofs:—

- Page 8, line 2, *read* intermediari animali di classe.
" " " 3, *read* allo sviluppo.
" " " 4, *read* il suo ciclo vitale, . . . parassita . . .
" " " 5, *read* e forse senza riproduzione.
" 9, " 22, *for* bef *read* bei.
" " " 32, *for* stezon *read* setzen.
" 17, " 27, *read* profond mystère.
" 20, " 39, *for* il y a disérieuses *read* il y a de sérieuses.
" 21, " 3, *for* le renvoi *read* le renvoi.
" 21, " 9, *for* peut où on obtenir *read* peut on en obtenir.
" 21, " 10, *read* ce dernier point est de la plus haute importance.

Pages various, *for* *B. hæmatobium* *read* *B. hæmatobia*.

It is stated, on p. 62, that at Ismailia unfiltered water is actually laid on to supply the bath-rooms in European houses. I am informed by the Public Health Department in Cairo that this is incorrect. The generalisation that unfiltered water was used in baths is based solely upon my own experience during a short stay in Ismailia.

PART I.
TRANSMISSION.



DISTRIBUTION OF *BILHARZIA HEMATOBIA*.

Key Map to Bibliography.

EGYPTIAN BILHARZIOSIS.

INTRODUCTORY.

THE lesions of bilharziosis are mainly due to the damage caused by the hard-shelled eggs of the parasite acting as foreign bodies in the tissues. Once the eggs are laid it is impossible to destroy them by treatment owing to the chitinous nature of the egg-shell. The effects continue with ever-increasing risk of complications and sequelæ for a number of years; until, in fact, the eggs succeed in escaping from the organ, bladder or bowel, in which they are deposited.

The only mode of dealing successfully with bilharziosis is to prevent its spread to uninfected persons.

The great economic loss resulting from widespread bilharzial infection was commented upon by Lord Kitchener in his annual report on Egypt for 1913, and the view is therein expressed that "it is high time that serious steps should be taken to prevent the continuity of infection that has been going on so long in this country."

The intractable character of the disease and the corresponding financial burden can be graphically illustrated from the experience of the Army. During the Boer War six hundred and twenty-five men were infected with bilharziosis in South Africa. In 1911, three hundred and fifty-nine of these were still on the list, exclusive of those meanwhile permanently pensioned. The cost to the State for "conditional" pensions for these three hundred and fifty-nine men was about £6,400 per annum. The "permanent pensions" already allotted amounted to an additional sum annually of £4,400 [128].

In the Nile Delta, bilharziosis is much more widespread and more severe in its manifestations than in South Africa. With the concentration of troops in Egypt it became desirable that the preventive measures taken against this disease should be made with a clear appreciation of the factors and the conditions under which

the disease is contracted and propagated. Unfortunately, although the parasitic nature of the disease had been established in 1851 nothing definite had yet been discovered of the life-cycle of the parasite or its manner of entering the human body. Early writers had supposed that the bilharzia worm, like other trematodes, required to undergo a metamorphosis in a molluscan intermediary before it became capable of infecting another person. In 1894, however, Looss formulated the hypothesis that the disease is communicable directly from man to man. In submission to his great authority in helminthological matters and his skill in dialectics, practically all research on the transmission of African bilharziosis undertaken during the last twenty years has been directed to the experimental verification of this hypothesis. During 1914 the author was in charge of the first Wandsworth Expedition of the London School of Tropical Medicine investigating the mode of spread of trematode infections of man in the Far East. Results which threw discredit upon the Looss hypothesis had just been acquired when the outbreak of war rendered field work impossible and necessitated an early return. The new facts were communicated to the War Office, and approval was given for the author to proceed to Egypt "to investigate bilharzia disease in that country and advise as to the preventive measures to be adopted in connection with the troops." Drs. R. P. Cockin and J. G. Thomson were associated with the author in the inquiry, and Private W. McDonald was transferred from the Sixth Essex (T.), as laboratory assistant.

The Committee of the London School of Tropical Medicine granted permission to all three members of their staff, while retaining their appointments, to accept temporary commissions for the period of the investigations. The requisite scientific apparatus was furnished by the School Committee. The Medical Research Committee (Insurance Act) allocated a special fund for all necessary field and other expenses incidental to the research. The Mission arrived in Egypt on February 8 and left again on July 15.

HISTORICAL.

Evidence of the occurrence of bilharzian disease in Egypt in ancient times has been found in early Egyptian records [388] and in the bodies of mummies now in the Cairo Museum [416]. In his *Memoirs*, Larrey [264] notes that symptoms of the disease were

frequent among the French troops during the Napoleonic Invasion of Egypt, 1799-1801. It was not until 1851, how-

DISCOVERY. ever, that the cause was recognized. In that year, Dr. Th. Bilharz, Assistant Professor at the Medical School in Cairo, wrote several letters to von Siebold announcing the discovery of a bi-sexual distome, which he named *Distoma hæmatobium*, and successfully establishing a definite relationship between this trematode worm and the symptoms of dysentery and hæmaturia resulting from the corresponding lesions of the intestine and bladder. These letters were published by von Siebold in the *Zeitschr. f. wissenschaft. Zool.* in the form of three articles during 1852 and 1853 [25], [26], [27].

GEOGRAPHICAL DISTRIBUTION. The disease occurs in most parts of Africa, in the outlying islands of Cyprus, Madagascar, Mauritius and Réunion; in Mesopotamia, West Indies, Porto Rico and Martinique especially, and in South America. Cases have occurred sporadically also in India, Australia, and England. The accompanying map gives the regions from which cases have actually been reported, with reference numbers to the papers in the Bibliography.

NOMENCLATURE. In 1858 Weinland [515] created a special genus *Schistosoma*, for the *Distomum hæmatobium*. In the following year Cobbold [92] discovered a similar parasite in the mesenteric veins of the sooty mangaby, *Cercocebus fuliginosus*. For this he used the new generic and specific terms, *Bilharzia magna*. Later, Cobbold accepted Leuckart's view that this species was identical with that described by Bilharz.

In 1864 Harley [214] showed that the endemic hæmaturia, common in certain parts of the Cape of Good Hope and Natal was due also to a species of *Bilharzia*, which he named *B. capensis*. Writing in 1871, Harley [216] confessed, "I have never had much doubt of the identity of the North and South African parasite, still, I can only deal with facts, and my position with regard to the question is pretty much the same as it was seven years ago. . . ." "Both Bilharz and Griesinger describe and figure *two* forms of egg, the one with a terminal and the other with a lateral spine. In all my own cases I can say positively that only one form of egg has existed, viz., that with a terminal spine. I have never seen any egg with even a tendency to the formation of a side spine." This differentiation of species was strongly opposed by Cobbold.

It would thus appear that the name *B. hæmatobia* was primarily associated by Bilharz with the parasites from the mesenteric veins

and those consequently concerned in the production of intestinal lesions, while the name *B. capensis* was proposed by Harley for that specially inducing vesical lesions.

In 1893 Manson [328] suggested, on grounds of dissimilar geographical distribution, that the vesical and intestinal forms of the disease were of separate origin. Adopting this suggestion, Sambon [425], in 1907, formally created a new species, *Schistosomum mansoni*, for the lateral-spined egg. Its validity was bitterly criticized by Looss [295], and the exact relation of this new name to the older specific names, *B. hæmatobia*, *B. capensis*, and *B. magna*, still remains to be finally established.

TERMINOLOGY. The disease has been variously named: (a) After the discoverer, bilharzia disease, bilharziosis, bilharziasis; (b) after the generic name of the parasite, schistosomiasis; (c) after the chief clinical manifestations, e.g., endemic hæmaturia, bilharzial dysentery, verminous cystitis, Cape hæmaturia, Egyptian hæmaturia; and (d) after the pathological situations, e.g., rectal bilharziosis, hepatic bilharziosis.

SEARCH FOR INTERMEDIARY. Bilharz does not appear to have made any observations upon the life-cycle or the probable mode of spread of the disease.

In 1854 Griesinger [200] conjectured that the young of Bilharzia "existed in the waters of the Nile, in the fishes which therein abound, or even in bread, grain, and fruit."

Harley [214], in 1864, wrote "according to the observations of Professor Siebold on the trematode worms, it may safely be assumed that between the ciliated embryo above described and the adult sexual animal there are probably two other distinct forms which serve to complete the chain of metamorphosis connecting these two extremes of development. What these forms are, and what their transmigrations, are questions which require careful elucidation. The ciliated embryo is adapted for an aquatic existence. Swimming freely about, these minute organisms probably come in contact with certain mollusca and become developed within them into what have been called cercaria sacs."

In his text-book on "Entozoa," published in 1864, Cobbold [95], after quoting Griesinger, remarks, "I think it is more probable that the larva, in the form of cercariae, rediae and sporocysts, will be found in certain Gastropod molluscs proper to the localities from whence the adult forms have been obtained."

The credit of having made the first attempts to trace the life-cycle through an invertebrate intermediary must be given to

Cobbold. His experiments, begun in 1870, were made in England with eggs obtained from persons who had returned from South Africa with hæmaturia. These experiments, which proved negative, are recorded in an article [101] "On the Development of *Bilharzia hæmatobia*," in 1872, in the following words:—

"I naturally sought for the possible intermediary bearers of *Bilharzia* among fresh-water molluscs and small crustacea. . . . I tried to induce the ciliated embryos to enter into the bodies of a great variety of animals such as gammarii, dipterous larvæ, entomotraca, limnæi, paludinæ, different species of planorbis, and other fresh-water molluscs, but neither in them nor in sticklebacks, roach, gudgeon, or carp, did they seem inclined to take up their residence. These experiments, however, are by no means conclusive, since the conditions under which the experiments were made departed in several respects from those that are presumably essential to success in the ordinary course of Nature."

The first, and in many respects the most sustained effort to elucidate the problem in an endemic area was made by the Italian helminthologist Sorsino, principally during the last two years of his stay in Egypt from 1874 to 1885.

The report of his "Ricerche sullo sviluppo della *Bilharzia Hæmatobia*," issued in 1884 [462], shows that Sorsino's investigation followed upon rightly conceived lines. Having accepted Chatin's view that the presence of germinal cells in the ciliated embryo indicated preparations for a metamorphosis as in other trematodes, he attempted, in the endemic area:—

(a) To infect, experimentally, mollusca kept in an aquarium.

(b) To find larval *Bilharzia* naturally infecting some species of mollusc or insect.

The following species are definitely listed as giving negative results—(a) to experimental infection: *Vivipara unicolor*, *Cleopatra cyclostomoides*, *Cleopatra bulimoides*, *Physa Alexandrina*, and *Melania tuberculata*, and (b) to dissection: *Vivipara unicolor*, *Cleopatra cyclostomoides*, *Cleopatra bulimoides*, *Physa Alexandrina*, *Melania tuberculata*, *Physa micropleura*, *Physa Innesi*, *Limnæa natalensis*, *Planorbis schweinfurthi*, *Unio campanii*, *Unio Jickeli*, *Corbicula* spp., and *Spatha caillaudi*.

The dissections revealed, however, a large number of trematode larvæ in the molluscs of Egypt. These developmental forms were described in a notable communication in 1892 [472].

From these investigations Sorsino concluded that "non è improbabile che la bilharzia che per tante particolarità s'allontana

dagli altri generi di distomi offre ancora questa singolarità di avere per ospiti intermediarii animali di classi diverse da quelle che servono allo sviluppo degli altri distomi o quella di compire tutto il suo ciclo vitalé in parte libero nell' acqua e in parte parassita in un solo ospite finale e forse senza riproduzione alternante."

In 1893-94, no fewer than three special missions visited North Africa to investigate Bilharzia transmission. Sonsino, then lecturer on parasites in the University of Pisa, proceeded to Tunis from Italy. The French Government sent Professors Lortet and Vialleton to Egypt. The University of Leipzig provided funds for Dr. Looss, Assistant to Professor Leuckart, to proceed to Alexandria.

Sonsino [469] reported that, after many experiments with different kinds of fresh-water molluscs (including *Melania tuberculata*, *Melanopsis præmorsa* and ? *Amnicola similis*) and arthropods, he had succeeded in obtaining evidence that a small crustacean was an infected intermediary host of Bilharzia; that the Bilharzia had a life-history differing from the typical one of the digenetic trematodes, as represented by *Fasciola hepatica*; that it required an intermediary host and underwent a metamorphosis, without asexual (or alternation of) generation, "thus resembling the holostomes"; that the free embryo having effected an entrance proceeded to encyst itself and that the encysted larva, being transferred with the crustacean in drinking water to the human stomach, was then set at liberty. After penetrating the intestinal walls, it arrived in the portal vein, where, presumably, it completed its development.

Further work led Sonsino [471], in the following year, entirely to withdraw these conclusions as untenable. In the same article he records without comment the discovery of larvæ in *Melania tuberculata* which he refers to *Cercaria ocellata* and which, as will be shown later in this report, is closely allied to Bilharzia.

Lortet and Vialleton [303] failed to transmit the disease directly to animals by feeding and inoculation, or to obtain infection of plants, aquatic arthropods, or molluscs; the following species of mollusca being specifically mentioned: *Unio ægyptiacus*, *Corbicula consobrina*, *Physa acuta*, *Vivipara unicolor*, *Lanistes carinatus*, *Lanistes boltenianus*, and *Melania tuberculata*.

Further experimental work was done by Lortet at Lyons in France, with several local species of Linnæa, but without success.

Later, in 1905, Lortet [302] published these "Expériences nouvelles sur le développement et la mode de pénétration du Bilharzia

hæmatobium": "Dans un aquarium nous avons versé tous les jours des embryons et des œufs de *Bilharzia* qui étaient ainsi mis en contact avec diverses espèces de mollusques aquatiques appartenant aux genres *Limnæa* et *Planorbis*.

"Dans quelques-uns de ces mollusques, nous avons rencontré des kystes que nous pensions être différents de ceux de la douve commune. Des milliers de ces mollusques que nous supposons devoir être infectés ont été ingéré, mêlés à du son, par un veau, des moutons, ainsi que par un singe. Les résultats ont été également négatifs."

Dr. Looss' report of his investigation is contained in a critical article [288] upon a paper of Dr. G. S. Brock [67]. His conclusions are copied here in extenso:—

"Als das Wahrscheinlichste und zunächst zu Erwartende war es natürlich anzusehen, dass der aus der Eischale befreite Embryo nach Art der übrigen Distomenembryonen in einen Zwischenwirt aus der Klasse der Weichtiere eindringe. Ich wiederholte bei den Experimenten in dieser Richtung die Versuche Cobbold's und Sonsino's, aber mit dem gleichen, durchaus negativen Erfolge. Weder bei den häufigsten Gasteropoden des Nildeltas (*Cleopatra bulimoides*, *Melania tuberculata*, *Vivipara unicolor*, *Lanistes carinatus*, *Physa Alexandrina*) noch bei Lamellibranchiaten (*Corbicula Caillaudi*) zeigte sich irgend eine Infektion, gleichviel, ob dieselbe bei Tage, im direkten Sonnenlichte, oder bei Nacht, ob sie bei erhöhter oder gewöhnlicher Temperatur, in grossen oder kleinen Bassins versucht wurde. Gleich negativ waren die Bemühungen, in denselben Mollusken, die auf oft mehrtägigen Exkursionen an notorischen Infektionsherden des Deltas gesammelt waren, irgend eine Cercarienform aufzufinden, welche auch nur mit einiger Wahrscheinlichkeit auf die *Bilharzia* hätte bezogen werden können. Namentlich diese letzteren negativen Erfahrungen sind es, welche mich veranlassen, die Mollusken jetzt definitiv als Zwischenwirte für unseren Wurm ausser Rechnung zu setzen. Derselbe ist in Aegypten so häufig, viel häufiger, als es die bisher veröffentlichten Statistiken die allerdings Stadt und Landbevölkerung gleichmässig betreffen, während ich mich bei meinen Untersuchungen hauptsächlich an die letztere hielt—nachweisen, dass man, falls eine Cercarie der *Bilharzia* im Freien existierte, sie daselbst sicher und auch häufig finden müsste. Und das um so mehr, als die Mollusken der Nilwässer ungemein häufig Cercarien beherbergen: 50-60 Proz. zeigen sich fast überall infiziert, an manchen Orten aber erwiesen sich von 100 untersuchten nur 2 frei von Parasiten!

"Dasselbe Resultat ergaben in ganz der gleichen Weise angestellte

Versuche mit Crustaceen und Insektenlarven (*Daphnia*, *Cyclops*, *Chironomus*, *Culex*, *Ceratopogon*, *Ephemera*, u.a.).

“Nicht glücklicher verliefen, nachdem so auch Crustaceen und Insektenlarven als mutmassliche Zwischenträger des Wurmes hatten von der Liste gestrichen werden müssen, entsprechende Versuche mit kleinen Würmern und Fischen.”

“Das eben betonte Verhalten der Embryonen anderen Tieren gegenüber war es nun auch wesentlich, welches mich schliesslich zu der definitiven Ueberzeugung brachte dass die Uebertragung der Embryonen mit Hilfe eines Zwischenträgers aus der Klasse der niederen Tiere nicht vor sich gehen könne. Es blieb deshalb nur noch die Möglichkeit übrig, dass der Embryo direkt in den Menschen gelange und dort zu einer Sporosyste auswachse, die ihre Brut dann an ihren Träger abgebe.”

Naturally, the most likely course and that which one expected *a priori* was for the embryo after escaping from the egg-case to penetrate, in a manner similar to that observed in other species of distoma, into some intermediate host appertaining to the class of mollusca. In my experiments in this connexion I repeated those of Cobbold and Sonsino, but with the like absolutely negative results. Neither in the most frequently occurring gastropods in the Nile Delta (*Cleopatra bulinoides*, *Melania tuberculata*, *Vivipara unicolor*, *Lanistes carinatus*, *Physa Alexandrina*) nor in the lamellibranchiates (*Corbicula Caillaudi*) was any sign of infection to be detected, whether the experiment was carried out in the day-time, in direct sunlight, or at night, whether at high temperatures or normal ones, whether in large or in small troughs. Equally negative were the results of attempts to find cercaria forms, which could with any probability be referred to *Bilharzia*, in samples of the same mollusca collected on excursions, sometimes extending over several days, from notorious foci of infection in the Delta. It is more particularly these latter negative experiences that induce me now definitely to exclude mollusca as the intermediate hosts of our parasite. The latter is of such frequent occurrence in Egypt, far more so than would appear from the published statistics—though I admit that these refer to both urban and rural populations, whereas my experiments refer mainly to the latter—that the cercaria form of the *Bilharzia*, if such exists in a free state, ought to be met with frequently and with certainty under such conditions. And this should be so all the more, considering that the mollusca found in the waters of the Nile harbour cercariae with remarkable frequency; nearly everywhere from fifty to sixty per cent. are found to be infected, and in some localities only two out of every hundred proved to be free from parasites.

Experiments conducted in a similar manner with crustacea and insect larvæ (*daphnia*, *cyclops*, *chironomus*, *culex*, *ceratopogon*, and others) yielded the same result. Crustacea and insect larvæ having had to be struck off the list of likely hosts of *Bilharzia*, analogous experiments were carried out with small worms and fish; the results were just as unsatisfactory.

The above described behaviour of the embryos towards other animals was in the main what led me finally to the definite conviction that probably no transference of the embryos by means of an intermediate host appertaining to the classes of the lower animals takes place. Hence the only possible solution that remained was that the embryo reaches man directly, and develops into a sporocyst in the human host, the offspring of the cyst being subsequently distributed to its host.

In 1896 Looss published, in “*Recherches sur la Faune parasitaire de l’Egypte*” [290], a detailed account of the larval forms

met with in the course of his dissections. With five exceptions these had already been described, in less detail, by Sonsino in 1895. It is noteworthy that seven of the forms described by Sonsino do not appear to have been found by Looss. The molluscs from which the larval forms were obtained belonged to the following species: *Vivipara unicolor*, *Cleopatra cyclostomoides*, *Cleopatra bulimoides*, *Physa alexandrina*, *Physa micropleura*, *Melania tuberculata*, *Limnæa natalensis*, and *Corbicula Caillaudi*, all of which had already been examined by Sonsino. A short time after the issue of this paper, Dr. Looss received an appointment on the staff of the School of Medicine in Cairo. His next contribution to the Bilharzia question was published in 1905, as a paper [294] on the "Histoire Naturelle de la bilharzia," read before the "Premier Congrès égyptien de médecine":—

"Des expériences . . . faites par Cobbold, en Angleterre, par Lortet, en France, et par moi, en Égypte, eurent, sans exception, le même résultat négatif. J'avais simultanément examiné des centaines d'exemplaires des différentes espèces de mollusques égyptiens recueillis dans des endroits où la bilharziose m'avait été rapportée comme étant très commune. S'il y avait un cercaire de la bilharzia correspondant à celle des autres distomes, j'aurais dû la trouver, mais je ne découvris rien de semblable. J'ai finalement observé au microscope la conduite des embryons de la bilharzia en présence des mollusques sus-mentionnés ou de fragments de leurs corps: or tandis que les embryons d'autres distomes qui se développent en réalité dans des mollusques, sont attirés même par des débris encore vivants du corps de ceux-ci et s'efforcent d'y pénétrer, les embryons de la bilharzia, eux, ne prêtaient pas la moindre attention aux mollusque que je leur avais présentés."

"Toutes les observations mentionnées et d'autres encore, tendaient donc à établir que les mollusques ne peuvent pas jouer un rôle dans le développement de la bilharzia."

In a polemical article, "What is *Schistosomum mansoni*?" in the *Annals of Tropical Medicine and Parasitology* for 1908, Looss [295] again asserts:—

"All attempts made by former authors to discover an intermediary host in which this development is gone through have failed, and so have my own efforts. I have examined hundreds of specimens of all the molluscs common in the Nile Valley without finding any sporocyst which might have been brought into relation with the Bilharzia worms. I have placed quantities of

free-swimming miracidia in contact with the same molluscs without obtaining an infection. It is easy to infect molluscs with miracidia of species which actually develop in them. *Bilharzia* miracidia were never seen to take any notice of any mollusc in their neighbourhood, whereas others developing in a certain mollusc soon begin to swarm about it, and may, under the microscope, even be observed to enter into it. The same negative results were observed with larvæ of insects, with fishes, and with plants. I am thus forced to the conviction that man himself acts as an intermediary host."

"In man, the miracidium must develop into a sporocyst which either directly or indirectly generates the *Bilharzia* worms. The only organ of the body thus far known to harbour young, and sometimes very young worms, is the liver. I therefore conclude that the liver is the habitat of the sporocyst from which the worms later escape into the portal vein."

In 1909, in a controversial paper entitled "*Bilharziosis of Women and Girls in Egypt in the Light of the Skin Infection Theory*," Dr. Looss [296] replies dogmatically to some brief comments on the insufficiency of his hypothesis made by Drs. Elgood and Sandwith at the Annual Meeting of the British Medical Association:—

"Any theory about the mode of infection with bilharziosis, in order to be at all acceptable, must (*a*) account for the passages of the miracidium both from man to water and from water back to man; it must (*b*) duly consider both the habits of the host and the biological peculiarities of the parasite.

"The theory of miracidium infection by the skin is in accordance with all the facts thus far known (*a*) of the biology of the parasite, (*b*) of the distribution of the disease among the population (native and foreign, town and rural) of Egypt. It shows (*c*) how the chief sufferers—the children in town, the adult males in the country—live under conditions which, from the epidemiological point of view, are essentially the same, and give the miracidia (*d*) the opportunity of passing, within the short time of their life, from man to water and from water back to man."

In a popular lecture [297] on the "*Life-history of the Bilharzia Worm*," before the Cairo Scientific Society in 1910, Dr. Looss again declared:—

"What we know of this, the life-history of the parasite, is the following:—

"The worms which infect a fresh subject originate from the

eggs which have left the preceding host with the urine or the fæces. The only medium in which they find the condition for further development outside man is water." "Authors have tried to find a mollusc capable of rearing the germs of *Bilharzia*; I have personally experimented with all the species occurring in the Nile Valley, but in vain. I equally failed with larvæ of insects living in water, with various species of fish, with plants, etc. In such circumstances the only alternative left was to assume that the germs from the water immediately return into man, making their way to the liver, where they reproduce the *Bilharzia* worms."

During 1911-13 Japanese investigators had succeeded in infecting cattle, cats, and dogs with an allied disease, caused by *Schistosoma japonicum*, by immersing the animals in the flooded fields of infected areas, but had quite failed to obtain infection by similar immersion in water containing large numbers of live miracidia. Commenting upon this in 1914, Dr. Looss [300] says:—

"Merkwürdig ist dass die japanischen Autoren anscheinend zu keiner Klarheit über die Natur der Invasionsform kommen können." "Nach [Miyawa] zeigt die Invasionsform einen so beträchtlichen Unterschied" von dem Mirazidium, dass die Existenz eines Zwischenwirtes wahrscheinlich wird. Ist dies richtig, dann müsste sich *B. japonica* in ihrer Entwicklung wesentlich von *B. hæmatobia* unterscheiden, denn wie ein im Wasser lebender Zwischenwirt an der Verbeitung der letzteren in den Städten Ägyptens beteiligt sein soll, scheint zunächst schwer verständlich."

It is remarkable that the Japanese authors do not appear to be able to come to any clear concept as to the nature of the invading form. According to Miyawa, the invading form manifests such marked divergences from the miracidium, that the existence of an intermediate host seems probable. If this statement is correct,¹ *Bilharzia japonica* must differ essentially in its development from *B. hæmatobia*, for it seems *a priori* difficult to understand how an intermediate host that lives in water can participate in the spread of *B. hæmatobia* in the towns in Egypt.

DIRECT The earliest attempts to obtain direct infection
INFECTION experimentally were made by Harley [216] in 1871.
EXPERIMENTS. "Two young rabbits and two dogs were allowed to take, at intervals with their food, pellets of the mucus containing swarms of the eggs. Three of these animals were killed after an interval of two, three, and six months respectively, and carefully examined, but no trace of *Bilharzia* could be found."

Mantey is reported to have made some experiments in 1880, but his account [331] has not been accessible. The results are quoted by Looss as having been negative. Lortet and Vialleton

¹ This has been experimentally demonstrated by Miyairi and by Leiper and Atkinson.

attempted to infect guinea-pigs by passing the Bilharzia eggs into the stomach through a tube. They also injected the eggs into the saphenous vein of rabbits, and also attempted to infect a Macacus monkey by mixing large numbers of eggs in its food. These experiments were uniformly unsuccessful.

Having convinced himself that the Bilharzia did not require an intermediate host, Looss [288] attempted, in 1894, to infect monkeys by the mouth.

“Die Versuche wurden jetzt so angestellt, dass die ausgeschlüpften Embryonen mit filtriertem Wasser ausgewaschen und dann in reines, ebenfalls filtriertes Wasser übertragen und mit diesem an verschiedene Tiere zum Trinken gegeben wurden. Mit dem Menschen selbst zu experimentieren, ging leider nicht gut an; es würde, glaube ich, in Aegypten auch kein einwandsfreies Resultat ergeben haben, denn fast jeder zweite oder dritte Mann ist dort bereits von selbst infiziert. Ich benutzte deshalb Affen verschiedener Species, bei denen ja durch Cobbold ebenfalls das Vorhandensein einer Bilharz konstatiert wurde. Die Tiere bekamen durch 6 und 8 Wochen hindurch täglich ein, zwei, teilweise sogar drei Mal von dem stark embryonenhaltigen Wasser zu trinken, dasselbe wurde teils in gewöhnlicher Temperatur, teils auf 37° C. erwärmt gegeben einer Temperatur, bei der sich die Embryonen ausserordentlich lebhaft und agil zeigen—die spätere Untersuchung (nach 8 und 10 Wochen) mehrerer Affen ergab aber in allen Fällen ein durchaus negatives Resultat!”

The experiments were now carried out as follows: the freed embryos were washed in filtered water and then transferred to clean, likewise filtered, water, and this was given to various animals to drink. It was unfortunately impossible to experiment with the human being; and, indeed, in my opinion no incontrovertible results would have been obtainable in Egypt by such a method, considering that practically every second to third person is already infected. I therefore employ monkeys of various species, Cobbold having shown that a Bilharzia is found to occur in them. During from six to eight weeks the animals were given some of this highly embryo-infected water to drink once, twice, and in some cases even three times a day; the water was given either at the ordinary temperature or at 37° C., the latter temperature being one at which the embryos are found to be extremely lively and agile; subsequent examination of several of the monkeys (after from eight to ten weeks) yielded in every case absolutely negative results.

SKIN The hypothesis that an unknown larval stage
INFECTION might enter the body through the skin had already
THEORIES. been formulated in the *Practitioner* for 1888, by
Allan [6], who wrote, “Nearly all the youths bathing in the Umzim-
dusi and Dorp Spruit are infected, while the girls, who do not bathe,
remain free of the disease.” In 1894 Brock [67] strongly supported
this view: “My own inquiries have led me to the conclusion that

bathing is, in this neighbourhood, at any rate, the most fruitful source of the infection. I cannot, among several hundred instances, recall one exception to the rule that all who suffer from the parasite have been in the habit of bathing. Moreover, it is among boys, who are fondest of swimming, that the symptoms earliest make their appearance; and I believe it would be hard, if not impossible, to find one boy much given to bathing in the streams, or their tributaries, who does not, before reaching manhood, become a subject of the disease. Only on this theory is explicable the fact noted by various observers in South Africa that the female sex is rarely attacked by *Bilharzia*.

“That the drinking of impure water is a common factor in the process of infection there is no lack of evidence; indeed, it would be unreasonable to think otherwise if the bathing hypothesis be well grounded. But, other things being equal, the chances of infection occurring will be greater from the large quantity of water which must come in contact with the body in bathing, than from the comparatively small amount conveyed into the stomach by drinking; so that, granting the larvæ to have the power of penetrating the body by some means, we should expect to meet with a much larger proportion of cases among bathers than among those who only drink the infective water.

“There is no evidence whatever that infection can take place by direct contagion. The question of how infection occurs will, however, only be satisfactorily solved when we have succeeded in tracing the development of the parasite, through all its stages.”

It was in an article (1894) criticizing this paper that Looss, while adopting the view taken therein that infection occurs through the skin, first maintained, on biological grounds, that the infective agent was the miracidium [288].

The biological facts upon which he based this deduction were explained by Looss [294] to the Egyptian Medical Congress in 1905, “il me sembla important de savoir si les embryons pouvaient, oui ou non, résister à l’influence des acides de l’estomac. J’ajoutai sur un porte-objet, au bord d’une goutte d’eau contenant quelques embryons vivants, un petit morceau de la muqueuse stomacale d’un singe récemment sacrifié et le comprimai légèrement pour en faire sortir quelque peu de suc. Dès que les embryons arrivaient à proximité de cette partie de la goutte, leurs mouvements cessaient presque instantanément. J’ai, plus tard, répété ces expériences avec un acide dont je connaissais la concentration. Une douzaine de larves, à peu près, ayant été recueillies dans un petit verre de

montre rempli d'eau pure dans laquelle ils nageaient aisément, une goutte d'une solution aqueuse d'acide hydrochlorique à un pour mille fut ajoutée avec précaution sur un côté du verre, mais sans mouvoir ce dernier. Aussitôt que les embryons, tout en nageant, entraient dans la zone acidulée, les mouvements de leur revêtement vibratile cessaient presque aussi vite que dans l'expérience avec le suc stomacal du singe. Les corps avaient encore quelques mouvements de contraction, mais au bout d'environ deux minutes les embryons étaient complètement morts. Peu à peu, huit embryons entrèrent de cette manière dans la zone acidulée et chez tous l'action de l'acide se montra absolument la même. L'expérience fut alors répétée, mais avec une solution d'acide à un pour deux mille. Même résultat que dans l'expérience précédente, avec cette simple différence qu'ici la mort définitive des embryons était un peu retardée.

“ D'après ces expériences, il me semble impossible que les embryons libres, avalés avec la boisson, puissent franchir vivants l'estomac de l'homme. Vu ce résultat, il ne reste donc plus qu'une possibilité pour les embryons de pénétrer dans le corps humain ; de percer leur voie activement à travers la peau. Il y a quelques années que j'ai été conduit à cette conviction à la suite d'observations spéciales, et je peux dire que les observations occasionnelles que j'ai faites entre temps, ne m'ont que confirmé dans mon opinion.”

“ Malheureusement, je ne peux pas encore vous fournir la preuve incontestable par l'expérience. J'ai déjà entrepris quelques tentatives pour faire entrer les larves dans des animaux, mais ces expériences, peu nombreuses du reste, et exécutées sans système, n'ont pas donné des résultats décisifs.”

The next attempt was made in German East Africa by Wolff, who failed to infect a cat by immersion for half an hour in water swarming with miracidia. His experiment is briefly recorded in *Archiv. f. Schiffs- und Tropenhygiene* for 1911 [521].

In 1912 F. E. Bour [51] wrote from Mauritius to the *Journal of Tropical Medicine and Hygiene*:—

“ Four months ago an attempt was made to infect two monkeys (*Macacus cynomolgus*), one by keeping for one and a half hours in the hollow of his abdomen, closely shaved, some water containing numerous miracidia ; the other by dropping the same water into his mouth and on the mucosa of his lips and cheeks. Up to the present time no Bilharzia eggs have been detected in their urine.”

In 1914 Conor [122] carried out an extensive series of experiments in Tunis to obtain direct infection. Miracidia were adminis-

tered to various species of monkey, to sheep, rabbits, guinea-pigs, and rats. Subcutaneous injection, applications to the shaven skin, attempts to infect by bathing and by the mouth, were without result in every case.

A number of experiments have also been made by Fülleborn, by certain of Dr. Looss's colleagues and by the author, but lacking success, these have not been put on record.

These repeated failures to obtain experimental verification of his theory are explained away by Looss [300] with the statement that man is the only known host of *Bilharzia hamatobia*.

It is right to add that a number of authorities, DISSENTIENTS, notably Blanchard and Manson, have consistently withheld their assent to the Looss hypothesis. In "Maladies parasitaires" Blanchard [37] wrote in December, 1895:—

"Il est hors de doute que l'embryon éclôt normalement dans l'eau et qu'il pénètre dans le corps d'un animal aquatique, pour y accomplir sa phase larvaire. Néanmoins on n'a pu jusqu'ici découvrir en quoi consistaient ses métamorphoses et chez quel hôte elles s'accomplissaient. Lortet et Vailleton . . . ont cherché l'embryon et la Cercaire dans les eaux des rivières et des mares d'Égypte au moyen de pêches au filet fin, sans pouvoir le rencontrer jamais. Ils ont dressé la liste des animaux qui vivent dans ces eaux et les ont examinés avec le plus grand soin, sans jamais y trouver aucun parasite qui soit imputable à l'une des phases de l'évolution de la Bilharzie. Le mode de développement et de propagation de ce Trématode reste donc encore entouré d'un profond mystère."

In 1905 Sir Patrick Manson [329], in his "Lane Lectures on Tropical Diseases" (p. 50), expressed the opinion that *Bilharzia* is "another illustration of the conveyance of a disease germ through water and probably by a fresh-water intermediary," while in the latest (1914) edition of his text-book on "Tropical Diseases" he writes: "Analogy suggests that the miracidium passes into the body of some fresh-water mollusc, crustacean, or larval arthropod, there to undergo the developmental changes in the redia and possibly the cercaria stages usually exhibited by the trematodes. Later, it may become encysted, and then, either free or still in the body of the intermediate host, gain access to man by penetrating the skin or through the stomach, and so pass to the veins of the portal system."

"Looss has expressed the opinion that, unlike other trematodes,

Schistosomum hæmatobium does not require the services of an intermediary host, and that the miracidium enters the human body directly by penetrating the skin." "I would remark that if *S. hæmatobium* does not require the services of an intermediary host its peculiar geographical limitations are difficult to explain."

In the following year Balfour [12] tentatively subscribed to the hypothesis that a minute crustacean was the essential carrier. He says: "In the first report the prevalence of the disease amongst the boys attending a primary school in Khartoum was mentioned. Many of these boys drank from the school well, and this water was submitted to examination. A tiny but very active entomostracean, probably belonging to the order *Ostracoda*, just visible to the naked eye, was seen.

"Six active embryos were placed in water along with three of the lively crustaceans and left over night. In the morning one dead embryo was found lying on the foot of the watch-glass, the other five had wholly disappeared, and the crustaceans remained alive and active. What had become of the missing five? Presumably they had entered or been taken up by the crustaceans."

Two years later (1908), in their "Review of Recent Advances in Tropical Medicine" [14], Balfour and Archibald add: "Time has not permitted further experiments with the species of *Ostracode* mentioned in the Second Report, but certainly the results obtained were suggestive."

LOOSS'S INDI- The practical requirements of his theory of
CATIONS FOR direct infection are indicated in the following
PROPHYLAXIS. abstracts from his publications during 1908-14:—

(1908.) *Ann. Trop. Med.* [295]: "If this conclusion [infection by miracidia] is correct, it leads to the important consequence that the spread of the *S. hæmatobium* is not limited by the natural geographical distribution of a special intermediary host. It can spread wherever man carries it, so long as, and in so far as, the climatic and hydrographic conditions are favourable for its development." "The Egyptian peasants usually work their fields in companies; sometimes of two or three, sometimes of several dozens, standing with their feet, and working with their hands, in the water or the mud. They often also bathe in companies in canals with slowly flowing water, pools, etc. One of them who is infected with urinary bilharziosis, when urinating into the water, infects it with several hundreds, perhaps thousands, of eggs. In warm weather the miracidia hatch within a few minutes. They have at once the opportunity of finding a new shelter, either in the skin of the man

who voided the eggs or in the legs and hands of one of his comrades working close by him. . . . These possibilities of infection are repeated every time a man urinates into the water. They are perhaps repeated every day the season of the Nile flood lasts."

(1909.) *Brit. Med. Journ.* [296]: "When once free from their eggs' shells they [the miracidia] disperse in the water to all sides, and the chance of reaching a suitable shelter considerably decreases for the individual miracidium with time and distance. The more I think of this latter circumstance the more I become convinced that the chief foci of infection—that is, the places where strong and repeated infections are contracted—cannot be found in large bodies of waters, as rivers, canals, ponds, etc., but must be sought in small accumulations of water, in which the miracidia, once introduced, cannot become widely dispersed."

"To render an infection of the skin at all possible . . . the following conditions must be realized: An infected person must urinate (or defæcate) in a place where there is water, however small the quantity. The place must remain moist for some time, but not longer than thirty to forty hours. Within this period another person must bring some part of his skin for some time into actual contact with the moisture. If these conditions are fulfilled the miracidia have the *possibility* of getting from man to water and from water back to man; their life-cycle may be closed.

"The infective power of moist places *gradually decreases* and is *again nil* at the end of one or two days even if they remain moist. A recent contamination must take place in order to render them infective again for a short period."

"The moist places demanded for infection are to be found plentiful about town: in the streets there remain puddles for several days after each rain or for several hours after each watering; the courtyards of the houses also are often watered especially in the warm season. In many Arabic houses water-closets are an unknown institution or they are of the most primitive type. The calls of Nature are often obeyed in the streets, oftener in the courtyards, especially for urinating. There is thus sufficient occasion for the ground to become over and over again populated with live miracidia: their short life is of no consequence. There only remains the host to supply the miracidia and another to take them up again."

"Contaminated water loses its infective power again after having been protected from fresh contamination for one or two days."

(1910.) [297] "Taking the [miracidium] infection by the way of

the skin as an established fact, the measures to adopt for preventing it are clearly given. First of all, infected persons should never evacuate urine or fæces into water, for this is the only way in which the latter becomes populated with the dangerous germs. If any body of water can be shown to be safe from contamination, it must, as a matter of course, be left out of consideration as a source of infection. If water is likely to be, or is likely to have been, contaminated, it should not be used for bathing, washing, or working in before about two days have passed. But even here a certain reasonable discrimination should be made. For in a large body of (standing or flowing) water, e.g., the Nile, any germs are soon so much dispersed that the possibility of picking up one or another becomes very small and may be increased only by a very prolonged contact with the water. Dangerous in the first place are small bodies of standing water, both permanent and transitory, because in these the germs cannot disperse."

In the last edition of Mense's "Handbuch der Tropenkrankheiten" (1914) he claims:—

"Besteht die Haut infektion in Wirklichkeit (sie wird neuerdings von immer zahlreicheren Autoren als wahrscheinlichen bezeichnet) so ist zu beachten, dass eine Auto-Reinfektion auch bei Wannenbädern möglich erscheint, wenn der Badende unter sonst günstigen Bedingungen (absichtlich oder unabsichtlich) Eier in des Wasser entleert."

If cutaneous infection really occurs—latterly an ever increasing number of authors mention such an infection as probable—it is worthy of note that auto-reinfection appears to be possible also when taking baths indoors, supposing the bather, other conditions being favourable (either intentionally or unintentionally), voids the ova into the water.

Blanchard's views on prophylaxis are expressed in the following passage from his "Traité de Zoologie Médicale" [34], 1899:—

"L'infestation se fait par les eaux de boisson, soit qu'on ingère l'hôte intermédiaire lui-même, et alors il s'agirait d'un mollusque de petites dimensions, soit plutôt qu'on avale la Cercaire nageant librement dans l'eau. . . ."

"On a supposé que le parasite pénétrait dans l'organisme à travers le peau et, par suite, on a interdit formellement les bains de rivière cette interdiction ne nous semble aucunement justifiée; encore que nous ignorons les phases ultimes du développement, il y a *admirables* raisons d'admettre que l'Helminthe pénètre réellement par la voie que nous avons indiquée plus haut. C'est donc l'usage d'eau non filtrée ou non bouillie qu'il faut rigoureuse-

ment proscrire dans les pays contaminés ; l'usage des bains est indifférent."

In 1908 in a brief note, "Le renvoi d'un Collegien atteint de Bilharziose est-il légitime?" in the *Archives de Parasitologie*, he wrote:—

. . . "il serait donc très utile de savoir où le jeune homme habite ordinairement. . . . quelle eau il boit ordinairement : eau d'une source vive, d'un puits ou d'une citerne? Y-a-t-il dans cette eau des mollusques ou coquillages et peut-on en obtenir des spécimens? Le dernier point est de la plus haute importance.

La bilharziose n'est pas une maladie contagieuse. Il n'y a donc aucune raison pour refuser de garder au lycée un jeune homme qui en est atteint : il n'est aucunement dangereux pour ses camarades."

Manson's opinion on prevention, as given in his "Tropical Diseases" [328] in 1905, is as follows:—

"Since analogy justifies the belief that the embryo of *Bilharzia* on obtaining access to fresh water enters a fresh-water animal and by it obtains access to another human host, it is evident that if the embryo be kept from getting into the water or if drinking water be boiled or filtered, the spread of the disease from man to man would be effectually prevented. In the endemic districts children in particular should be carefully and repeatedly warned against drinking the water of ponds and canals. Provided reinfection be avoided by the exercise of prudence in the matter of drinking* water, there is no necessity for sending the patients with *Bilharzia* disease away from the country in which the parasite was acquired."¹

In a popular lecture to the Rhodesia Scientific Association [330] in January, 1914, Sir Patrick Manson said, after briefly outlining the development of the liver-fluke : "In a similar way I believe the germ of *Bilharzia* disease, so common in this country, especially in young people and probably contracted in bathing in pools and rivers, is acquired and spread."

INCIDENCE OF BILHARZIOSIS IN EGYPT.

The published statistics of the incidence of Bilharziosis in Egypt have been based mainly upon hospitals records. Reliable statistics are notoriously difficult to obtain in Egypt, owing to the ignorance

¹ In the fifth edition (1914) the above paragraph is slightly changed by the addition of the words "or bathing in" after "repeatedly warned against drinking" and by the deletion of the word "drinking" marked by an asterisk *.

and suspicion of the mass of the people and their deep-rooted objection to having their names or affairs set down in any paper or book that may form part of the Government archives. Such an ordinary chronic condition as Bilharziosis is frequently not thought worthy of mention in addition to any other disease the patient may wish treated or which may be the cause of death. There are certain beliefs, too, apparently considerably prevalent, which not infrequently account for concealment. Many cases, therefore, go entirely untreated and unrecognized.

Griesinger [201] found 32 per cent of infections in 363 autopsies made in Cairo up to 1856. Sonsino [453] obtained 46 per cent from 91 autopsies. In 1894 Kauffman [321] recorded from 500 autopsies that 369 males gave 40 per cent and 131 females gave $11\frac{1}{2}$ per cent, i.e., a general average of 33.3 per cent with Bilharzia. Ferguson [168], in 1910, stated that his observations, based on considerably more than 1,000 post-mortem examinations at the Kasr Aini Hospital in Cairo, revealed the presence of this disease in no less than 40 per cent of Egyptian male subjects between 5 and 60 years of age. In 1905 Milton [346] showed that 930 patients were treated for Bilharzia as in- or out-patients at Kasr Aini Hospital during 1901.

In 1910 Professor Madden [321] published the figures from the annual reports of the Kasr Aini Hospital for the three years 1907-09, showing a total number of admissions for medical and surgical diseases 11,698, of which 1,270, i.e., about 10 per cent, had Bilharziosis. These cases represent only persons "suffering from pathological destruction of kidneys, ureters, bladder, urethra, and rectum, produced by severe and repeated bilharzial infections." Madden adds, "the mortality from Bilharziosis *per se* or its immediate complications was just over ten per cent; but this hardly gives one even an approximate idea of the real mortality, as many cases, when they do not appear to be improving, are taken out of hospital to die at home; all such cases are entered as unrelieved, but had they been left in hospital many of them would certainly soon have been included in the mortality tables." Professor Ferguson found that of a series of five hundred autopsies on male subjects eight per cent of all cases died of the effects of severe bilharzial infection.

In the course of the ankylostomiasis campaign during 1914-15 MacCallum obtained for the first time some exact and detailed information regarding the local incidence of vesical Bilharziosis in the provinces of Qaliubia and Sharqia. These results have not yet been published, but Dr. MacCallum very generously communicated

his statistics to assist the present inquiry. In Qaliubia, of 700 persons examined 44 per cent showed vesical Bilharziosis. In Sharqia, 66 per cent of the 1,089 patients attending the travelling hospital for ankylostomiasis at Minia el Qamh, and 70.9 per cent of 832 attending at Bilbeis showed Bilharzia eggs in the urine.

THE MOLLUSCA OF EGYPT.

The fresh-water molluscs of Egypt have been studied by a number of malacologists, and have been well described and illustrated, especially by Jickeli (1874) in "Fauna der Land und Süßwasser Mollusken Nord Ost Afrika's," by Bourguignat in various papers from 1863 to 1883, by Innes (1884) and Pallary (1909). The last writer, in his "Catalogue de la Faune Malacologique d'Egypte," summarizes very completely the work of previous collectors. Pallary's list (excluding land forms) is given in the adjoining table and in parallel columns are indicated: (a) Those species previously described in the works of Jickeli in 1879; (b) the species mentioned as having been examined as possible transmitters of Bilharzia in the writings of Lortet and Vialleton, Sonsino, and Looss, and marked respectively by the lettering "V." "S." "L."; and (c) the forms collected and examined in the course of the present inquiry. It will be seen that of the fifty forms catalogued by Pallary, Lortet and Vialleton mention only four, Sonsino specifies nine, and Looss eight. It will be noted that all the forms mentioned by Looss had been examined also by Lortet and by Sonsino. In the subjoining table is tabulated a complete list of the trematode larvæ hitherto found in Egyptian molluscs. A comparison of the finds of Sonsino and Looss shows that each investigator met with developmental forms overlooked by the others, and that the investigations of the present inquiry revealed a still larger number of new forms.

In the Natural History section of the magnificent "Description de l'Egypte" prepared by the authority of Napoleon during the French occupation in 1799-1801, eight of the commonest fresh-water molluscs are recorded and beautifully illustrated. In three of these we have found undoubted Bilharzia larvæ within half an hour's journey by tram and train from Cairo.

These are extraordinary facts in the light of Professor Looss's repeated contention during the past twenty years that he had examined hundreds of specimens of all the molluscs occurring in the Nile Valley without finding any developmental form which might have been brought into relation with the Bilharzia worm.

As every digenetic trematode hitherto investigated has been found to undergo its larval metamorphosis in a mollusc, the deductions made by Looss from investigations ranging over such a restricted part of the molluscan fauna of Egypt are entirely unwarranted. The conclusion of Lortet and Sonsino, that their inquiries had failed to reveal the essential invertebrate intermediary, was much more reasonable.

THE PRESENT INQUIRY.

As the province of Qaliubia had been shown to be heavily infected with bilharziosis it was decided to make Cairo the headquarters of the inquiry. It will be seen from fig. 1 that the province of Qaliub adjoins Cairo immediately to the north, lying between the eastern (Damietta) branch of the Nile on the west and the desert on the east, and is easily accessible by road and rail, being traversed by the highway and main line to Alexandria and their subsidiaries. At the request of Sir David Semple, Chief of the Public Health Department of Egypt, the vacant laboratories of the Professor of Parasitology in the School of Medicine in Cairo were kindly set apart for our use by the Director, and facilities for the keeping of experimental animals were provided at the Bacteriological Institute. The C.M.S. Hospital at Old Cairo constantly supplied fresh material for observation from their clinical cases. The programme of work laid down and consistently followed was :—

(a) To collect and specifically determine all the fresh-water molluscs in the selected endemic area, i.e., within half a day's journey from the laboratory in Cairo.

(b) To dissect large numbers of all species found for trematode larvæ.

(c) To differentiate among the larvæ found those showing the morphological characters peculiar to the bilharzia group.

(d) To ascertain which, if any, species of mollusc showed chemiotactic attraction for *Bilharzia miracidia*.

(e) To induce experimentally infection of animals brought from England with *Bilharzia cercaria* when found in the mollusc.

(f) To ascertain experimentally whether infection took place through the skin or by the mouth or in both ways.

(g) To ascertain experimentally the incubation period of the disease.

(h) To determine experimentally on infected animals the efficacy of medicines, reputed to be of value on clinical grounds, to destroy the bilharzia worms in the portal system.

EGYPTIAN SPECIES OF MOLLUSCA.

Pallary, 1909			Jickeli, 1874	S., V., L., 1892-94	W.O. Mission, 1915
(1) <i>Succinea cleopatra</i>	+	..	+
(2) <i>Physa acuta</i>	+	V.	+
(3) <i>Physa subopaca</i>	-	..	+
(4) <i>Limnæa Caillaudi</i>	-	..	+
(5) (var.) <i>Raffrayi</i>	-	..	-
(6) <i>Limnæa alexandrina</i> (= <i>natalensis</i>)	+	S. L.	+
(7) <i>Limnæa truncatula</i>	+	..	?, +
(8) <i>Limnæa pharaonum</i>	+	..	+
(9) <i>Bullinus brocchii</i>	-	..	?
(10) <i>Bullinus Dybowski</i>	-	..	+
(11) (var.) <i>alexandrina</i>	-	S. L.	+
(12) <i>Bullinus Imesi</i>	-	S.	+
(13) <i>Bullinus (Isodora) truncatus</i>	-	..	+
(14) <i>Bullinus (Isodora) contortus</i>	+	..	+
(15) <i>Bullinus (Pyrgophysa) forskali</i> (= <i>Physa micropleura</i>)	+	S. L.	+
(16) <i>Planorbis (Menetus) boissyi</i>	+	..	+
(17) <i>Planorbis (Menetus) alexandrinus</i>	+	..	-
(18) <i>Planorbis (Menetus) poeteli</i>	+	..	-
(19) <i>Planorbis (Menetus) Laurenti</i>	-	..	+
(20) <i>Planorbis (Tropidiscus) philippi</i>	-	..	-
(21) <i>Planorbis (Gyraulus) Ehrenbergi</i>	-	..	?
(22) <i>Planorbis (Gyraulus) mareoticus</i>	+	S.	+
(23) <i>Planorbis (Segmentina) letourneuxi</i>	-	..	-
(24) <i>Planorbis (Segmentina) angusta</i>	+	..	+
(25) <i>Ancylus clessini</i>	-	..	?
(26) <i>Ancylus Isseli</i>	+	..	+
(27) <i>Ampullaria ovata</i>	+	..	+
(28) <i>Ampullaria kordofana</i>	-	..	-
(29) <i>Ampullaria lucida</i>	-	..	-
(30) <i>Ampullaria exigua</i>	-	..	-
(31) <i>Ampullaria vitrea</i>	-	..	-
(32) <i>Lanistes bolteni (carinatus)</i>	-	V. L.	+
(33) <i>Vivipara unicolor</i>	+	S. V. L.	+
(34) <i>Vivipara biangulata</i>	-	..	+
(35) <i>Cleopatra bulimoides</i>	+	S. L.	+
(36) <i>Cleopatra vexillata</i>	-	..	-
(37) <i>Cleopatra verreauxi</i>	+	..	-
(38) <i>Cleopatra cyclostomoides</i>	-	S. L.	+
(39) <i>Bythinia goryi</i>	+	..	-
(40) <i>Bythinia alexandrina</i>	-	..	-
(41) <i>Bythinia letourneuxi</i>	-	..	-
(42) <i>Bythinia pseudannicola</i>	-	..	-
(43) <i>Bythinia subbadiella</i>	-	..	-
(44) <i>Bythinia (Gabbia) semmaarica</i>	+	..	+
(45) <i>Hydrobia erythraea</i>	+	..	-
(46) <i>Hydrobia stagnalis</i>	+	..	-
(47) <i>Hydrobia (?) schweinfurthi</i>	+	..	-
(48) <i>Melania tuberculata</i>	+	S. V. L.	+
(49) <i>Valvata nilotica</i>	+	..	+
(50) <i>Neritina nilotica</i>	+	..	-

(i) To observe the conditions favourable and inimical to the life of the free-swimming cercaria and the effect thereon of acid solutions and other medicinal substances.

(j) To study the bionomics of the special molluscan intermediary, if obtained, for facts upon which prophylactic measures could be formulated.

An examination of the banks of the Nile to the south of and around Gezireh, an island opposite Cairo, showed that, excluding bivalves, there were very few living forms in the main stream. Similar results followed from an examination of the Ismailia Canal at Mataria, north of Cairo, and of the Giza Canal, on the western bank of the Nile.

A study of a map of the environs of Cairo showed that there was a large number of collections of water in the Zoological and Botanical Gardens at Giza. With the permission of the Director, Major Flower, these ponds were exhaustively examined and were found to contain nearly all the described species of molluscs, with one or two notable exceptions. With material from this source a type collection of molluscs was made so that specimens brought in later from infected areas could be rapidly compared and determined.

In the report of the ankylostomiasis campaign in Qaliubia it was noted that a small travelling hospital had been stationed at the village Qalama, thirteen miles north of Cairo and near the main road to Alexandria (fig. 1). Of ninety-five inhabitants of this village, forty-three had been found to harbour bilharzia. This small village seemed, therefore, at first sight, a suitable place in which to make an intensive study of the local molluscan fauna. It proved, however, more difficult of access than had been anticipated. There was, too, a very large pond or birket which could not be thoroughly examined. Finally, as will be noted from the map, the canal outskirting the village had passed through a number of other villages after it took off from the main stream. Infection acquired in Qalama might well have been due to infective larvæ carried on from a higher part of the canal, and not actually derived from molluscs at Qalama itself. It was consequently decided to seek a more suitable village, if possible (a) of easy access, (b) without a birket, and (c) on a small canal coming almost directly off one of the main supply canals.

EL MARG AND THE MARG CANAL.

In the meantime, the Arab who had been for many years attendant in the Department of Parasitology had volunteered to bring snails from a place where he had been in the habit of

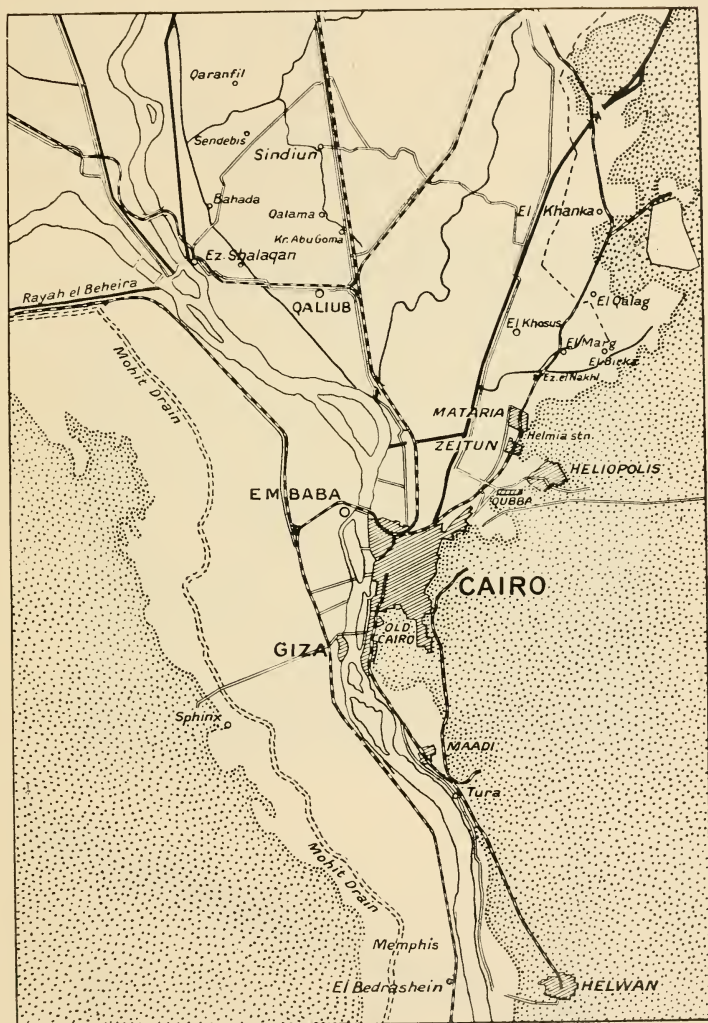


FIG. 1.—Cairo and the outlying villages,

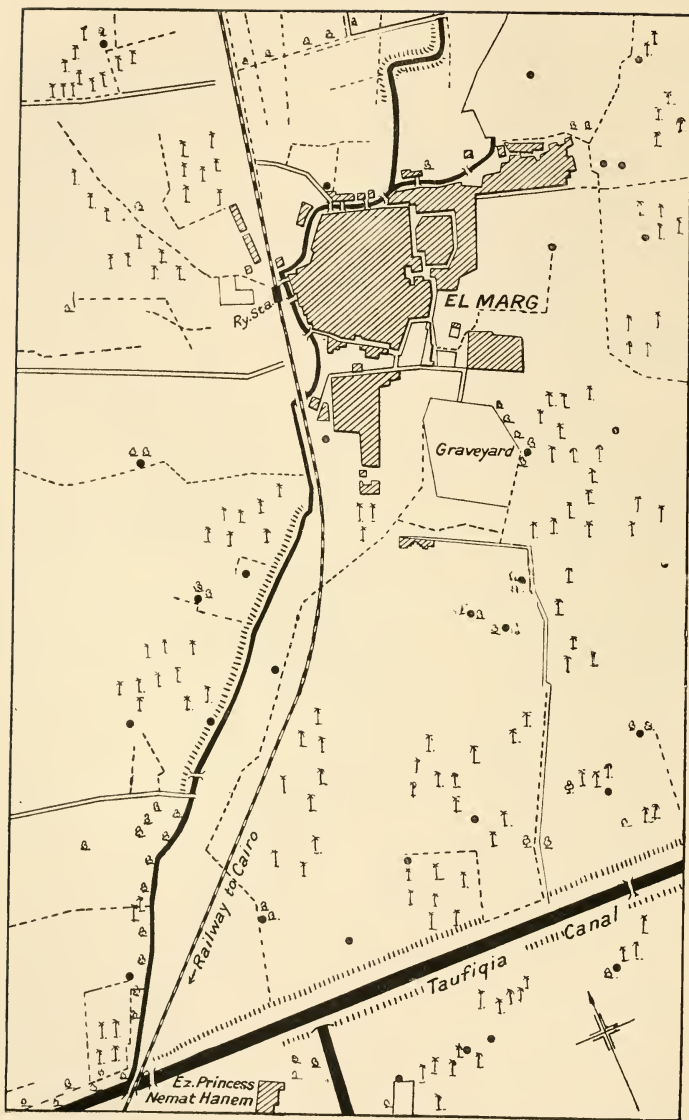


FIG. 2.—El Marg and the Marg Canal.

collecting them for the purposes of the class in zoology. His finds were both numerous and varied, and it was decided to prospect this collecting ground. It proved to be at his own village, El Marg, some nine miles north of Cairo, just beyond the popular and rapidly extending northern suburb of Cairo on the Zeitun-Mataria line. There was a good half-hourly train service, the village lay alongside the railway line and was an agricultural centre, being surrounded



FIG. 3.—Children from Marg village collecting water for domestic use.

by cotton fields and date palm groves. There was no birket, the only water supply to the surrounding fields was a small tertiary canal which traversed the village and derived its supply from the main Ismailia Canal a few miles distant, not far from its origin from the Nile. The village has a population of less than 5,000 and its inhabitants are mainly occupied in cultivating the surrounding land.

As will be seen from fig. 1, El Marg is situated in the centre of a cultivated plain, roughly triangular in shape, having as its base the Ismailia fresh water canal which runs north from Cairo, and

limited on the other two sides by desert. From the irrigation standpoint this triangle forms a small unit, the incoming water being drawn from the Ismailia Canal, mainly by the secondary Taufiqia Canal, which can be seen running eastward north of Mataria through Ez-el-Nakhl, where it is crossed by the railway from Cairo to El Khanka, and passing on through El Birka. The water from this canal and its subsidiaries, such as the El Marg Canal, after irrigating the land, drains into the large Bilbeis



FIG. 4.—Women washing garments in Marg canal.

drain, which runs northward from El Birka past El Qalag to Bilbeis, and is indicated on the map (fig. 1) by a broken line. The El Marg Canal takes off from the Taufiqia Canal near Ez-el-Nakhl station, and the flow is here controlled by an iron regulator. For about a mile the canal runs northwards parallel to the railway line, and on either bank there is a much frequented footpath. Just before the Marg railway station is reached, the canal passes under the line. At and above this point are the favourite spots from which the women and children carry water daily into the village for domestic use (fig. 3). After piercing



FIG. 5.—The canal skirting the village between the railway station and the cafés.



FIG. 6.—Marg bridge, crossing the canal from the station.



FIG. 7.—The canal forming a shallow pool in the village square.



FIG. 8.—Marg canal running northwards through the village.



FIG. 9.—The Marg Canal traversing the date palm grove.



FIG. 10.—Marg Canal entering the cotton fields north of the village.

the railway embankment the canal continues alongside the line for about one hundred yards. This reach is much frequented by women for the purpose of washing clothes (fig. 4). The canal now skirts the houses, shops and cafés which front the railway station, and is open to constant contamination (fig. 5). A short wooden bridge crosses the canal at the station (fig. 6). Here the stream bends towards the centre of the village and forms a wide



FIG. 11.—A cul-de-sac in Marg canal dry during the "rotations."

shallow pool (fig. 7). Turning northwards again between two rows of houses, and with paths on either bank (fig. 8), it laces through a date-palm grove (fig. 9) and reaches the open country, where it rapidly diminishes (fig. 10) and ultimately divides into a number of small canals supplying the individual fields.

INCIDENCE OF BILHARZIOSIS IN MARG.

In the historical section reference was made to the frequent occurrence of bilharziosis among the French troops during the invasion of Egypt in 1799-1801, and it is of interest that the little village Marg was the site of one of the battles in 1799.

No statistics of the occurrence of bilharzia in this village were obtainable. A rapid examination of the urine of fifty-four boys in two of the village schools showed bilharzia eggs in forty-nine cases. The determinations were completed within an hour, and the positive results based upon single drops of freshly passed urine taken without either sedimentation or preliminary use of the centrifuge. Most of the boys were under 12 years of age, and had been born and reared



FIG. 12.- Marg Canal almost dry during a summer rotation.

in the village. It seemed reasonable to suppose that the bilharzia infection was derived from the Marg Canal, with its terminal branches and subsidiary agricultural drains around the village. It was decided, therefore, to make a complete census of all fresh-water molluscs in this the sole possible source of infection.

THE MOLLUSCA OF MARG.

A fortunate circumstance enabled us to make practically certain that no species living on or in the muddy bottom of the canal was overlooked. During the summer months the water coming from

the main canal is entirely controlled by the Government, and is supplied on a definite rota of six days' flow, succeeded by fifteen days' stoppage, in every three weeks. This rotation began early in April. During the fifteen days' stoppage the water entirely disappeared from the Marg Canal (fig. 11), save where inequalities left small puddles (fig. 12), and we were able to collect stranded shells throughout its length from the drying surface and to recover by sieving those forms that had succeeded in burrowing for some distance into the mud. The species found were: *Melania tuberculata*, *Vivipara unicolor*, *Cleopatra bulimoides*, *C. cyclostomoides*, *Bullinus dybowski*, *B. alexandrinus*, *B. contortus*, *B. innesi*, *Pyrgophysa forskali*, *Lanistes bolteni*, *Planorbis boissyi*, *P. maroticus*, *Limnaea Caillaudi*, *Bythinia (Gabbia) sennaarica*, *Valvata nilotica* and some bivalves.

The commonest species were *Planorbis boissyi*, *Bullinus* and *Cleopatra*, *spp.*, the two first-mentioned being the most obvious forms on account of their habit of seeking the surface for air.

TECHNIQUE.

The various molluscs, wherever and whenever collected, were separated into their different genera and, as far as possible, species, and examined for developmental stages: (a) by direct inspection, (b) by dissection. When an infected mollusc is kept in a glass vessel in clean water for a few days the cercarial forms are frequently discharged naturally by the mollusc, and may be easily seen swimming about in the water if the glass is held against the light and examined with a hand lens. By this method large numbers of the same species can be placed together in a vessel and tested without further technique. If, however, the larval development has not yet reached the stage for the discharge of the cercaria the results are apt to be misleading. Should a positive result be noted, the cercaria can be determined by microscopical examination and the infected mollusc isolated and kept alive for further observation. By dissection the earlier stages (sporocyst, redia, and immature cercaria) are obtained. The method has the disadvantage that the mollusc is necessarily killed in the course of the dissection and cannot be used for further work. The technique is simple though tedious when large numbers are involved. The shell, when hard and calcareous as in *Cleopatra* and *Melania*, is crushed with lion forceps, placed on a slide in a drop of water or weak formalin and the mass then torn apart with two dissecting needles. With the thin-shelled forms like *Planorbis* it suffices to fix the shell by piercing the central whorl with one

needle and to cut outwards with the second. In our experience the spear-shaped steel points issued for use on gramophone records when fixed in needle-holders are far more satisfactory than ordinary dissecting needles for this work. With them a large window can be quickly cut in the hardest shells and the molluscan body rapidly dragged out complete. The liver, which occupies the upper or central whorls of the gastropod shell, is the usual site of election for the developmental stages of trematodes. But a detailed examination of the mollusc is practically never necessary for the determination of an infection. With the first tear, as a rule, the characteristic bodies flood out in numbers into the surrounding plasma and water, while further search may be made under a low power by squashing the whole molluscan body slightly between two slides. In this way over 3,300 samples were minutely examined in the course of the inquiry. As shown in the appended list, seventeen species of Trematode larvæ were identified during these dissections. A number of new species were found also.

LIST OF TREMATODE LARVÆ IDENTIFIED IN EGYPTIAN MOLLUSCS.

Molluscan host	Name of larva	Sonsino 1892	Looss 1896	Leiper 1915
Cleopatra	(1) <i>Gastrodiscus ægyptiacus</i>	—	+	+
	(2) <i>Cercaria distomatosa</i>	+	+	+
	(3) <i>Cercaria vivax</i>	+	+	+
	(4) <i>Cercaria exigua</i>	—	+	+
	(5) <i>Cercaria microcotyla</i>	+	—	+
	(6) <i>Cercaria capsularia</i>	+	+	—
	(7) <i>Cercaria cristata</i>	+	—	+
Limnæa	(8) <i>Cercaria obscura</i>	+	—	+
Bullinus	(9) <i>Cercaria pigmentata</i>	+	·	+
	(10) <i>Cercaria agilis</i>	+	—	+
	(11) <i>Cercaria fissicauda</i>	+	—	+
B. (Pyrgophysa)	(12) <i>Cercaria pigmentata</i>	+	+	+
Melania	(13) <i>Cercaria pleurophocercu</i>	+	+	+
	(14) <i>Cercaria cellulosa</i>	—	+	+
	(15) <i>Cercaria monostomi verrucosum</i>	—	+	+
	(16) <i>Cercaria microcristata</i>	+	—	+
	(17) <i>Cercaria microcotyla</i>	+	—	+
Vivipara	(18) <i>Cercaria pusilla</i>	—	+	+
Lanistes	(19) <i>Cercaria sp. ?</i>	—	?	+

RECOGNITION OF BILHARZIA CERCARIA.

The adult bilharzia worm resembles the other distome trematodes in possessing well-developed oral and ventral suckers, but differs in two remarkable ways: the sexes are separate, and there is an absence of a definite muscular pharyngeal bulb at the commencement of the œsophagus (fig. 21). As in all parasitic worms the infective

stage shows no sexual differentiation, consequently the absence of pharynx in the cercaria (fig. 19) is the one reliable character upon which a bilharzia cercaria can be distinguished from the cercariæ from other distomes, because the body of the cercaria without further metamorphosis grows to become the body of the adult worm. All cercariae have a motile tail at the posterior end. This appendage is a purely larval structure both morphologically and functionally. It serves the definite object of enabling the cercaria body to travel from the intermediate host to some favourable position where it can gain entrance to the final host. The tail is always shed before the actual arrival of the cercaria in the tissues of its host. Various cercariae exhibit different types of caudal appendage. In the four bilharzia cercariae that have come under the notice of the writer the tail was forked at its free end. This peculiarity, however, is shared with some other widely different forms among the distomes. It will be shown in the latter part of this report that four distinct sub-groups of bifid-tailed cercariae occur in the mollusca of Egypt.

ATTRACTION OF MOLLUSCA FOR BILHARZIA MIRACIDIA.

Looss states that none of the Egyptian mollusca exhibited the slightest attraction for the freshly hatched miracidia of bilharzia. Most of the species submitted to experiment by us were entirely ignored by the miracidia. A definite attraction, however, was exhibited by the following: *Planorbis boissyi*, *Bullinus* sp. (?), *Pyrgophysa forskali*, and *Limnæa truncatula*. The attraction was stronger in young specimens. This plurality of susceptible forms appeared to indicate the possibility of a plurality of intermediate hosts or the susceptibility of the *Bilharzia hæmatobia* miracidia to the intermediate hosts of other species of bilharzia, or merely, as seemed probable in *Limnæa truncatula*, to a peculiar adhesiveness of the mucus covering the exposed portion of the mollusc body.

It may be noted here that not a single specimen of *Limnæa truncatula* could be found in or around Marg.

MARG MOLLUSCS FOUND INFECTED WITH BILHARZIA.

Large numbers of snails collected from the Marg Canal throughout its course, but more especially within the village, were infected with larval forms showing the morphological peculiarities of the bilharzia group. The infected shells were readily obtained at spots daily frequented, such as the praying ground at the embankment

crossing (fig. 11), in front of the cafés (fig. 5), and at a bend in the canal specially used for washing, which is illustrated in fig. 10.

The same species of mollusc was quite common at some distance from the village in the agricultural drains away from foot-paths, but was not infected. Nearer the village, however, and especially where crossed by public paths, these drains contained infected snails (fig. 13). So far the molluscan intermediary has



FIG. 13.—A typical agricultural drain on the outskirts of Marg, containing infected snails.

not been found in birkets, but it occurs not uncommonly in large marshes such as that, lying to the south-west of Ismailia, which is illustrated in fig. 14.

Once a bifid-tailed cercaria has been placed in the bilharzia group on account of the absence of pharyngeal bulb, further determination of its systematic position can only be effectively established in the first instance by experimental infection of a susceptible host and the subsequent examination of the adult worm resulting therefrom.

ATTEMPTS TO INFECT ANIMALS EXPERIMENTALLY.

Three cercariæ of bilharzial type were found in four different species of molluscs. The first form met with differed considerably from the other two, more especially in possessing a pair of black pigment spots just anterior to the ventral sucker, and a delicate but well-defined cuticular expansion on each side of the two prongs of the bifid tail. This form was found exactly five weeks after the



FIG. 14.—Marsh, near Kosti village, south-west of Ismailia.

commencement of our search, and occurred in *Planorbis maroticus* collected from the ponds in the Zoological Gardens at Giza. Apparently identical cercariæ were found later at Giza and Suez in *Melania tuberculata*, and at Ismailia in *Planorbis boissyi*. The second bilharzia cercaria occurred in large numbers in *Planorbis boissyi* at El Marg, and was found later in similar canals between Inshas and Bilbeis in the Sharqia province. A very few cercariæ, apparently identical with this, were recovered on one occasion only from a *Melania tuberculata* in the Zoological Gardens. A third

cercaria, which on morphological grounds was only provisionally distinguished from that occurring in *Planorbis boissyi*, was also found at Marg in a certain number of specimens of *Bullinus* (fig. 15, A).

At Marg the *Planorbis boissyi* (fig. 15, B) were so commonly infected with non-eyed *Bilharzia* cercaria that half-an-hour's collecting sufficed to ensure a large supply of active larvæ. An extended series of experiments was instituted to determine the specific character of these forms.

Three species of *Bilharzia* worms are supposed to occur in Egypt: In man the *Schistosoma hæmatobium* (both varieties), in cattle the *S. bovis*, and in ducks the *Bilharziella polonica*. As bifid-tailed cercariæ with eye spots have been found, though not identified, in snails both in Central Europe and in North America, and as this cercaria departed somewhat from the two other forms, it seemed a reasonable conjecture that this cercaria was the larval



FIG. 15.—A, *Bullinus cortortus*; B, *Planorbis boissyi*.

stage of an avian *Bilharzia*, and that the two remaining and similar cercariæ probably attained their maturity in the two known mammalian hosts. Attempts were made to verify this conjecture experimentally. In order to exclude possible fallacies it was essential to infect ducklings immediately after hatching and before they had come in contact with other than filtered water. These were not obtainable in Cairo.

One was struck by the apparent entire absence of rats in the banks of the canals and in the fields. The authorities at the Giza Zoological Gardens stated that the common water-vole does not occur in Egypt. A professional rat-catcher was commissioned to obtain rats and field-mice from around Marg. His search proved quite fruitless. It was possible that this extraordinary absence of rodents might be due to a susceptibility to *Bilharzia* disease.

The animals frequenting the canal at Marg were man, cattle,

sheep, dogs (possibly rats), geese, ducks, chickens, and crows. Man and cattle were the most obvious sources of contamination of the canal water, and as each was a known host of species of *Bilharzia*, the probabilities were that cercaria normally developed in them.

Attempts to infect a calf and a lamb by allowing water heavily charged with the living cercaria to remain in the hollows of the groin for periods of ten to thirty minutes on several days gave entirely negative results at the post-mortems some weeks later. It was noted, however, in the case of the lamb, that the skin, where repeatedly exposed to infection, became markedly red.

A series of experiments was then made on mice, rats, geese, ducks, chickens, crows, and wagtails. The experiments on the birds proved entirely negative.

A positive result became apparent by June 13 in a young white rat, which had been infected on May 4. A black mouse which had been infected on May 2 died on June 24 with a number of *Bilharzia* worms in the liver and mesenteric veins.

In these early successful infections the mice and rats died from the occlusion of the portal system before the *Bilharzia* worms had reached sexual maturity. A comparative study of mature specimens of *Schistosoma bovis* and *S. hamatobium* showed that these two species are so closely allied that, when experimentally reared in an abnormal host, a differential diagnosis could only be made with certainty upon the characters of the fully grown worms, and especially upon those of the egg shell. Further experiments were made. In those animals which survived for seven to eight weeks, female worms were found containing the characteristic eggs (fig. 20). This placed the diagnosis beyond question.

The animals used were variegated mice and white rats brought from London and fed solely on oats and filtered water. They had been kept in the laboratory under conditions entirely precluding the possibility of unobserved infection.

ANIMALS FOUND SUSCEPTIBLE TO INFECTION.

In addition to tame white rats and variegated mice, the Egyptian desert rat, obtained from the neighbourhood of the Pyramids, was found to be susceptible to experimental infection, while guinea-pigs were peculiarly so. Mangaby monkeys died of acute bilharziosis within two months of infection. Experiments were not made on dogs owing to the quarantine difficulties that would have arisen on our return to England. At the conclusion of its field work the Mission



FIG. 16.

Edge of liver of mouse experimentally infected with bilharzia.

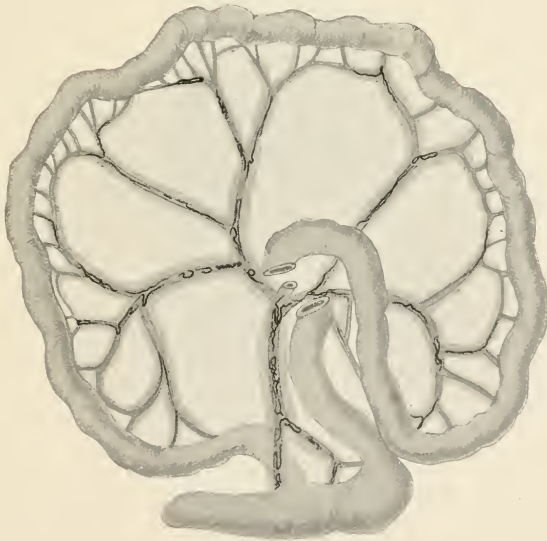


FIG. 17.

Mesentery of mouse experimentally infected with bilharzia.



FIG. 18.

Section of liver of white rat experimentally infected with bilharzia showing veins blocked by worms.

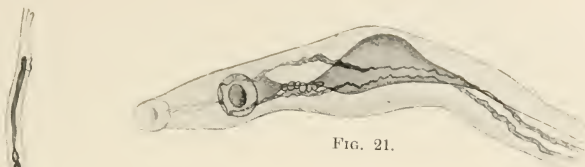


FIG. 21.



FIG. 20.



FIG. 19.

- Fig. 19.—Cercaria of *Bilharzia* used in experiment. $\times 200$.
 Fig. 20.—Adult female taken from portal vein of mouse, experimentally infected mouse. $\times 18$ (circa).
 Fig. 21.—Anterior portion of adult male taken from the same source. $\times 18$ (circa).



brought back from Egypt four mice, twenty-six white rats, sixteen desert rats, two guinea-pigs, and four mangaby monkeys, which had been submitted to infection shortly before departure. When examined shortly after their arrival in England all these animals had enormous numbers of bilharzia worms in the portal system.

EFFECT OF WEAK ACID AND ALKALI ON LIVING MIRACIDIA AND CERCARIA.

The theory that Bilharzia infection takes place through the skin was put forward by various South African writers from Harley to Brock, because in their clinical experience infection was found to follow repeatedly upon bathing in heavily contaminated waters. Looss, on the other hand, adopted the view because weak acids were found to kill the miracidium and consequently this, his hypothetical infective agent, could not survive in the stomach when taken in drinking water. The favourable action of weak alkalis and the destructive effect of dilute acids on all cilia is one of the recognized exercises in practical physiology. That alkalis and acids should have a similar effect on the ciliated body of the miracidium may be regarded therefore as a foregone conclusion. It does not necessarily follow, however, that the same result would obtain in the case of cercaria which are covered with a cuticular skin. Experiments were undertaken therefore to ascertain exact information on this point. Looss and others have shown that miracidia are killed immediately by a dilution of 1 in 2,000 of hydrochloric acid. Cercariæ withstand hydrochloric acid 1 in 880 for five minutes; 1 in 500 kills Bilharzia cercaria immediately. The acidity of the stomach would therefore inhibit these cercaria. This does not exclude the possibility, however, that infection may take place through the mouth. The ankylostomes and strongyloides infect through the mouth as well as through the skin. Fülleborn has recently shown that when the strongyloides are taken in by the mouth they do not pass on directly in the lumen of the gut into the small intestine, but penetrate the wall and, gaining the blood-stream, follow the circuitous route through the lungs up the trachea and then pass for a second time down the œsophagus through the stomach to the small intestine.

MODE OF ENTRY OF BILHARZIA INTO THE BODY.

That something similar to this might occur in Bilharzia was suggested by a simple observation on the habits of the Bilharzia cercaria. These cercaria progress by swimming mainly through the

activity of their tails or by creeping by means of their well-developed suckers. When actively swimming cercaria are poured from one dish into another it is very noticeable that they immediately fix themselves firmly by means of their ventral suckers to the surface of the vessel into which they are carried until the motion of the water has ceased, when swimming is again resumed. It seemed, therefore, quite possible that if heavily infected water was drunk, the cercaria, coming into momentary contact, might similarly adhere to the mucous membrane of the mouth, tongue and œsophagus and at once proceed to penetrate into the tissues. That this actually can take place is apparently borne out by the following experiment. Four sooty monkeys which had been taken out with the Mission in January and kept in separate cages in the laboratory until the experiment was completed, were subjected to infection with *Bilharzia cercaria*. In three cases the infected water was poured into the bottom of the cages and the monkeys were consequently exposed to infection through the skin of the hands, feet, buttocks and tail. The fourth monkey was fed for a day or two on dry food only, and then allowed to drink from a cup containing filtered water swarming with *Bilharzia cercaria*. Some effect, probably a prickly sensation, was produced almost immediately, for the monkey began to pull down the lower lip, to rub the mucous membrane of the mouth, and in other ways to indicate that the drink had not been pleasurable. After a second experience on the following day the monkey refused to accept water out of a cup although thirsty. The four monkeys eventually died and all showed a heavy infection with *Bilharzia*. The monkey infected from drinking water showed earlier and much more intense symptoms than the others. This experiment showed that in *Bilharzia* infection may be both oral and cutaneous. As in ankylostomiasis there is little doubt, however, that the infection enters through the skin in the bulk of cases.

As Brock [67] has pointed out, the chances of infection are much greater in bathing than in drinking, because under the former circumstances a much larger quantity of water comes into contact with the body.

INCUBATION PERIOD OF THE DISEASE.

The incubation period of *Bilharzia* has been variously estimated by different writers. Sonsino gives from two to three years. Sandwith considers that it ranges from three to six months.

Hatch [222] in 1887 wrote: "The time between the contraction

of the disease and the passage of blood and other symptoms may be very short; one patient, who stayed at an hotel at Suez for fourteen days, suffering from them a month after his return to Bombay." More extensive observations were made during the South African War. Beveridge [24] gives the following valuable table in the JOURNAL OF THE ROYAL ARMY MEDICAL CORPS for 1907:—

Case	Age	Service year	Date of arrival in South Africa	Date of reporting sick with Bilharzia ova in the urine	Interval between arrival and reporting sick	Remarks
1	20	1	9.11.02	1.2.03	12 weeks	
2	20	1	9.11.02	17.2.03	14 "	
3	20	1	9.11.02	6.2.03	4 months	
4	21	1	9.11.02	19.3.03	4 "	
5	20	1	9.11.02	20.3.03	4 "	
6	23	3	9.11.02	6.7.03	7 "	Gives a history of 4 months' duration.
7	16	1	4.12.02	19.6.03	6½ "	Gives a history of 3 days' duration.

In the same year Dr. Stock [475] wrote: "The time which elapses between its entrance and the onset of symptoms seems to be settled from the observations of Dr. Abercrombie. During the time that the regiment was at Pretoria several young drafts were sent out direct from England and all in due course bathed in the spruit, and as a result several cases occurred in young soldiers whose residence in the country had not been more than two months. The shortest period observed was one month, and the longest two months."

A similar incubation period occurred in the monkeys infected by us experimentally. Monkey No. 1, infected by immersion on June 15, 17, 24, and July 11, passed bilharzia eggs on August 4 and died on August 18. Monkey No. 2, immersed on June 17, 20, 23, and July 11, passed blood and mucus containing bilharzia eggs on July 30 and died August 9. Monkey No. 3, immersed June 17, 20, 23, and July 11, showed bilharzia ova in the wall of the large intestine after death on August 2. Monkey No. 4 drank infected water June 24, and on other occasions, including July 11, passed schistosome eggs and blood on August 4 and died of acute bilharziosis on August 8.

OCCURRENCE OF BILHARZIOSIS IN LARGE TOWNS.

There is one argument brought forward in his numerous papers by Professor Looss which seems at first sight to lend real support to his view that the mollusc is not required for the bilharzia

worm ; that is, the accepted occurrence of bilharzia infection among children born and bred in large towns such as Cairo, where there is a filtered water supply.

Looss states that 33 per cent. of the boys attending a school in Cairo showed bilharzia eggs in the urine, and in 1908 Mrs. Elgood [158] showed that out of forty girls aged 12 to 16 in a middle-class school in Cairo, 11 (i.e., 27·5 per cent) were infected. These girls with one exception had lived all their lives in Cairo. None had ever bathed in the Nile or a canal, nor had any ever run about



FIG. 22.—Courtyard of Department of Physical Science, Cairo, showing supply of unfiltered water pumped direct from the Nile.

bare-legged in fields or country roads. The general water supply in Cairo is the same for natives as for Europeans, is of high quality and is supplied from the filters of the Cairo Water Company. These facts have been repeatedly used by the supporters of the Looss hypothesis, and certainly if correct could scarcely be otherwise explained.

After some inquiry the following facts came to light, which seemed to afford a simple and adequate reply to this objection. In

addition to the series of pipes supplying Cairo with filtered water, it appears that there is a second system carrying to the numerous gardens of Cairo unfiltered water drawn direct from the Nile in the neighbourhood of the Kasr Nil bridge, a spot where, in recent years, numbers of European troops have, while bathing, become infected shortly after their arrival in Egypt. It is well known that the children, even of the better-class Egyptians, are allowed to run about in the privacy of their own courtyards in a state of semi-nudity during the summer months, and are thus continually exposed to the risk of infection from the hose used in the garden or stable. The lower classes probably derive their infection from the same source, although under different circumstances. To them water is a dear commodity in Cairo. There is no free supply. In the poorer quarters one frequently sees water being hawked about in large skins, and there is the standing inducement to the middleman to increase his margin of profit by arranging to draw his stock, possibly surreptitiously through a friendly gardener, from the unfiltered supply for which the water companies make a lower charge. At Ismailia there is a dual supply of filtered and unfiltered water into the houses, the latter being laid on to the bathroom and kitchen and supplied at a lower rate. A standard pipe from the unfiltered supply in Cairo is shown in fig. 22 from a photograph taken in the courtyard of one of the Government offices.

CONCLUSIONS CONTRASTED.

CONCLUSIONS
BASED ON
THE LOOSS
HYPOTHESIS.

- (1) All transient collections of water, such as those resulting from occasional showers of rain, road waterings and domestic waste, are dangerous if freshly contaminated.
- (2) Large bodies of water, such as the Nile, canals, marshes and birkets, are little liable to be infective.
- (3) All water in a given area would automatically become safe in thirty hours if the native infected population were removed.
- (4) Infected troops would be liable to reinfect themselves, to spread the disease among other troops, and to convey the disease to any part of the world.
- (5) Infection only takes place through the skin.
- (6) Infection in towns is due to contact with recently contaminated moist earth or water.
- (7) Eradication depends upon education and complete sanitary control throughout the country. The sustained co-operation of the affected individual is essential.

CONCLUSIONS (1) Transient collections of water are quite safe
BASED ON THE after recent contamination.
RESULTS OF (2) All permanent collections of water, such
THE PRESENT as the Nile, canals, marshes and birkets, are
INQUIRY. potentially dangerous, depending upon the presence of the essential intermediary host.

(3) The removal of infected persons from a given area would have no effect, at least for some months, in reducing the liability to infection, as the intermediate hosts discharge infective agents for a prolonged period.

(4) Infected troops cannot reinfect themselves or spread the disease directly to others. They could only convey the disease to those parts of the world where a local mollusc could efficiently act as carrier.

(5) Infection actually takes place both by the mouth and through the skin. Recently contaminated moist earth or water is not infective.

(6) Infection in towns is acquired from unfiltered water which is still supplied, even in Cairo, in addition to filtered water, and is delivered by a separate system of pipes.

(7) Eradication can be effected without the co-operation of infected individuals by destroying the molluscan intermediaries.

PART II.
PREVENTION AND ERADICATION.

WATER IN RELATION TO THE SPREAD OF BILHARZIA.

WITH the knowledge that the infective agent of Bilharziosis is the cercaria, and that this can only develop in certain molluscan intermediaries, we have to consider whether anything can be done to control the spread of the disease. Professor Madden, who possesses, perhaps, the most intimate acquaintance of bilharziosis in all its clinical manifestations, wrote in 1910 that "among the Egyptian people generally there exists a widespread endemic disease, responsible for much suffering and a very considerable mortality among the agricultural population particularly, which we, as the controlling powers of the public health of the country, have done nothing to try and prevent." "Only those who are conversant with the habits and ways of the people are capable of judging of the apparent hopelessness of the task; but it is surely time that a beginning should be made with it, though along what lines it is not easy to indicate."

It was hoped by the authorities in Egypt that the preventive measures now being applied to ankylostomiasis would also prove efficacious in dealing with bilharziosis. These comprise free treatment, the introduction of conservancy, and the dissemination of knowledge of the disease amongst the natives. Such measures would appear, however, to be of little value in the control of bilharziosis, for the following reasons:—

(1) In ankylostomiasis treatment not only rapidly cures the individual patient, but by killing the adult parasites also assists in limiting the spread of the disease. In bilharziosis there is no recognized treatment other than merely palliative.

(2) In ankylostomiasis the disease is spread by the fæces only. In bilharziosis both urine and fæces would require control. The introduction of conservancy would not necessarily ensure the immunity of canals and the smaller streams of water from contamination with urine in agricultural districts.

(3) The co-operation of the natives in Egypt could only follow upon years of instruction resulting in a radical change in the habits of the people.

The remedy is to be sought elsewhere. Fortunately, there are certain physical conditions almost peculiar to Egypt which are inimical to the cercaria and its carrier, and which, if properly exploited, might bring about almost complete eradication of the disease in the course of a few years.

Water is absolutely essential for the life of the *Bilharzia* outside the body. In Egypt all water is derived from the Nile, directly by irrigation canals or indirectly by seepage into wells, and from rain.

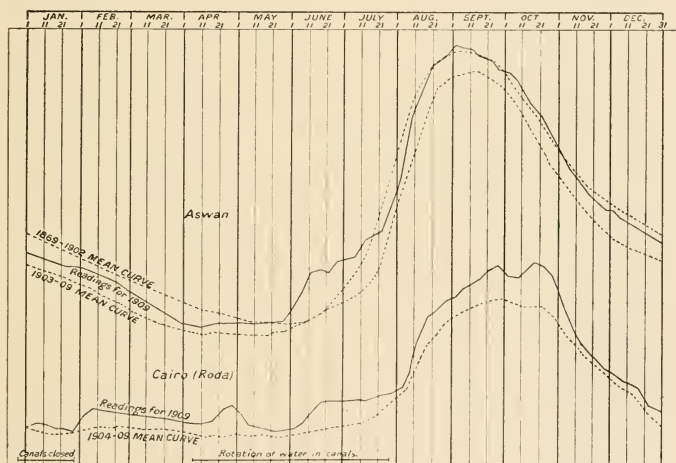


FIG. 23. — Showing annual rise in the Nile during the autumn.

THE NILE: IRRIGATION.

Almost the whole of the water required for the cultivation of the land and for the use of the population is derived from the Nile. Until 1820 the cultivated land was irrigated by the Nile only during its annual rise. The land at the river's edge is ordinarily about nine metres above the river-bed. Every autumn the river rises from seven and a half to ten metres above its bed, as shown in the accompanying diagram (fig. 23). In the early days of Egyptian

history the Nile at these times inundated the whole of the valley. As the population increased, huge dykes were built parallel to the banks of the Nile, and from these other dykes were made stretching from the river to the hills to form large compartments or basins. During the flood the turbid waters of the river were led into these basins by artificial canals, and allowed to saturate the soil thoroughly and to deposit their rich mud on the surface. When each basin was properly irrigated, the water was allowed to pass on into other basins at a lower level, and eventually to return into the Nile when the flood had sufficiently receded to allow this.

According to Willcocks and Craig, this system of "basin" irrigation was in operation over the whole country through the times of the Pharaohs, Ptolemies, and Romans, down to the Arab Conquest in the seventh century. Between 700 A.D. and 1800 A.D. the dykes were uncared for and irrigation was abandoned over the greater part of the delta. The population gradually dwindled from 12,000,000 to 2,000,000. In 1821 Mohamed Ali changed the whole system by excavating a number of deep canals capable of drawing off the waters of the Nile at low level during the summer. This allowed of the cultivation of a summer crop and thus brought about the introduction of cotton upon a large scale. An area of over 3,100,000 acres is now perennially irrigated in Lower Egypt. In 1874, a quarter of a million acres in Upper Egypt and the whole of the Fayum were similarly converted from basin to perennial irrigation. The completion of the Assiut and Assouan barrages have been steps in the conversion of further large areas. At the present day the whole of Lower Egypt under cultivation is irrigated from canals which run throughout the whole year, while in Upper Egypt 964,000 acres are now also perennially irrigated, while 1,287,000 acres still receive their waters in basins through canals running only in flood. During a low flood the amount of water available is not sufficient to keep the whole area under cultivation. Those lands thus thrown out of cultivation are termed "Charaki" and are exempted from taxation (p. 53). With the extension of perennial irrigation the amount of "Charaki" is being continually diminished.

The extension of perennial irrigation has resulted in a marked increase in the prosperity of the people. The population has again risen to over 12 millions. At the same time, perennial irrigation appears to have encouraged the spread of bilharziosis. The disease is much more common at the present day in the Delta and in the Fayum than in those parts of Upper Egypt still supplied only with

RÉPARTITION PAR MOUDIRIEHS DES TERRES "CHARAKI," 1899-1912.

Années	Totaux	Assiout	Assouat	Bent Souef	Gaerga	Gizeh	Kena	Minia	Béhéra	Dakah- lieh	Char- bieh	Kaï- oubieh	Menoufieh
1899	352,213	35,075	34,508	10,342	75,813	38,258	132,567	17,492	1,254	204	87	690	2,893
1900	19,038	2,341	2,906	1,957	1,933	4,130	1,171	4,483	117	..	..	..	..
1901	12,845	1,231	1,618	1,455	1,245	4,000	726	2,132	438	..	..	..	..
1902	186,151	11,642	16,629	3,617	18,965	17,718	105,129	11,162	586	..	32	307	364
1903	5,158	611	2,164	426	524	224	322	867	..	..	..	..	..
1904	55,075	4,343	12,940	1,561	1,745	6,118	22,938	5,126	203	..	..	..	101
1905	47,147	4,190	10,397	1,811	2,634	6,177	15,855	5,683	213	..	..	..	187
1906	2,756	5	1,513	..	781	98	113	207	39	..	..	..	..
1907	124,671	6,994	15,947	1,776	16,229	10,185	65,139	8,181	170	..	..	..	50
1908	125	..	..	..	..	125	..	..	..	..	..	..	..
1911	377	11	16	83	..	17	5	235	10	..	..	..	..
1912	25,845	2,873	9,344	643	2,730	744	2,378	6,968	8	9	4	..	144

Ce sont les terres soumises au régime des bassins lesquelles, pendant les années de bas étiage, restent incultes faute d'eau et sont par conséquent exemptées de l'impôt foncier. La superficie de ces terres tend naturellement à diminuer avec l'extension du système de l'irrigation permanente. (From *Annuaire Statistique de l'Égypte*, 1914.)

basin irrigation. This has been remarked upon by Milton. In the Records of the Egyptian Government School of Medicine for 1904 he states:—

“Cairo is on the dividing line between Upper Egypt and the Delta, and patients come to Kasr-el-Ainy for treatment from all parts of the country; still the disproportion between the number of cases of bilharzia drawn from the two natural divisions of the country is so very marked that there must be some very well defined cause constantly acting, and this, I believe, is to be found in the way in which water is supplied to the different provinces for the purposes of irrigation. The provinces of Lower Egypt are supplied with water for irrigation all the year round, or practically so, whereas the Upper Provinces are supplied with water for irrigation only during and after the time of High Nile. Thus the peasant from Lower Egypt has a much longer period of time during which he is exposed to the chance of infection, and infection is more frequently repeated than is the case with his brother of the Upper Provinces.

“The province of Ghizeh is a case very much in point, for here, although it borders immediately on Cairo, and although Cairo is its hospital town, the proportion of its population per 100,000 coming for treatment for bilharzia is but 9·75 as compared to Sharkieh 19·85, Qalioubieh 18·06, and Menoufieh 13·47, the three other provinces adjoining the capital, but then Ghizeh is basin irrigated, whereas the other provinces named are perennially irrigated.”

The relative frequency of bilharziosis in perennially irrigated areas may be due in part to continued liability of the workers to infection as suggested by Milton, but the favourable environment created for the propagation of the intermediate host is probably a much more important factor.

Subsoil water is generally derived from local rainfall, but in Lower Egypt it is practically all the result of seepage from the Nile and its canals. **THE NILE: SUBSOIL WATER.** The average thickness of the Nile alluvium is said to be about seven metres, below this is a layer of sand and gravel into which the river-bed dips. Through this layer, when the river is in flood, a natural flow of water takes place and the static head of the river in flood is thus transmitted to great distances, causing a rise in the level of the subsoil water. This rise is sometimes actually visible, for low-lying land near the river may become covered with water. The subsoil water of the deep sand and gravel strata is utilized for the water supply of towns and for purposes

of irrigation in Upper and Middle Egypt and in the southern half of the Delta. In the fields it is not an uncommon sight to see the water being lifted from deep wells by means of Persian wheels or "sakias," as they are termed in Egypt, driven by one or two blindfolded animals: usually buffaloes, but sometimes camels and bullocks (fig. 24). The "sakia" consists of a vertical wheel carrying an endless rope, slung with earthen pots or buckets which dip into

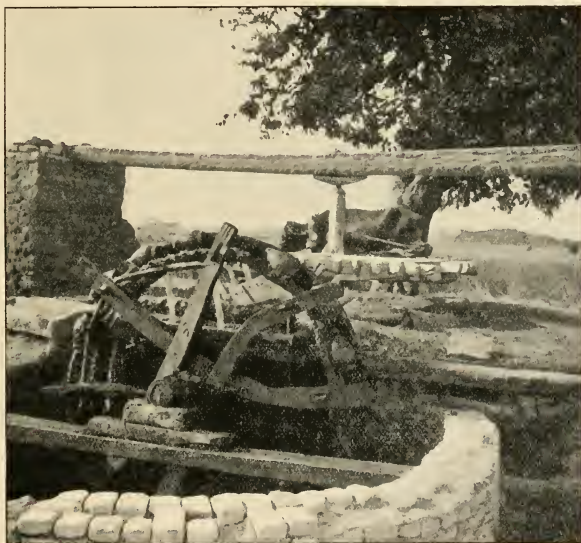


FIG. 24.—A "sakia" in use in the fields near Marg.

the water. On its axle is a rough wooden-cogged wheel actuated by another cog-wheel placed horizontally. This wheel is moved by a pole fixed at one end to the axle and at the other to the neck of the animal being used to turn it.

According to Mr. Crawley there are five thousand two hundred and fifty-five "sakias," and two thousand two hundred and ninety wells with engines and pumps, drawing subsoil water in fields in the Lower Egypt Irrigation Inspectorate.

The rainfall in Egypt is at no time enough of itself to moisten the soil sufficiently for agricultural use, and is confined to the winter months from October to April. As will be seen from the accompanying table, no rain was recorded from any part of Egypt during the months of June, July, August, and September. Mr. Hurst, of the Physical Science Department of Egypt, has examined the official records for the last twenty years, and has found that an absence of rain during these months has been constant.

MONTHLY RAINFALL IN MILLIMETRES DURING 1912.

Station	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Alexandria (Mex)	14	26	7	0	0	0	0	0	0	Drops	1	26
Port Said ..	23	58	8	0	6	0	0	0	0	Drops	Drops	9
Suez ..	Drops	1	0	0	0	0	0	0	0	0	0	4
Ismailia ..	10	6	6	Drops	0	0	0	0	0	Drops	0	6
Cairo, Ezbekia..	3	9	Drops	Drops	0	0	0	0	0	Drops	0	5
Giza ..	4	9	Drops	Drops	0	0	0	0	0	Drops	0	2
Abbassia..	0	7	0	0	0	0	0	0	0	Drops	0	3
Kafr el Zayât ..	9	19	Drops	0	4	0	0	0	0	6	1	9
Tanta ..	10	17	2	0	3	0	0	0	0	1	Drops	10
Kafr el Dawar..	28	58	6	Drops	2	0	0	0	0	1	1	40
Damanhur ..	15	28	7	Drops	3	0	0	0	0	1	Drops	23
Shebim el Kom	2	14	Drops	0	2	0	0	0	0	0	0	4
Damietta ..	67	30	10	Drops	7	0	0	0	0	16	3	17
Manzala ..	13	20	4	Drops	Drops	0	0	0	0	Drops	0	Drops

The average rainfall per annum at Cairo during the last nineteen years is only 3·28 centimetres. Willcocks and Craig estimate that the amount of the Nile water used on the Delta to irrigate the crops corresponds approximately to a rainfall of 1·30 metres, i.e., fifty-one inches per annum.

PROTECTIVE MEASURES.

The life of the bilharzia outside the body may be divided into three periods: (1) That between the passage of the egg into water and the entrance of the hatched parasite into the mollusc; (2) the stage of metamorphosis within the mollusc; (3) that prior to the entrance of the free-swimming cercaria into the human body after it has left the mollusc. It is universally recognized that in Egypt under present circumstances it is practically impossible to prevent the contamination of water with infected urine and fæces. In order to break the life-cycle of the bilharzia worm one must find some simple means of destroying it during the free-swimming infective stage, or of depriving it of its essential intermediate host.

The former is the line of attack suited to the conditions under which bilharziosis is acquired in large towns; the latter is applicable to country villages and districts.

PREVENTION OF BILHARZIOSIS IN TOWNS.

It has been shown earlier in the report that bilharziosis is frequently contracted by young children in the city of Cairo. The infection could have been derived only from the public water supply, and it was suggested that the unfiltered water supplied throughout Cairo by pipes for garden and stable purposes was the most likely source. This water is pumped from the Nile where infections are known to have been contracted. It has been our experience that very few gastropod molluscs could be found on the banks of the Nile in the neighbourhood of Cairo. It is obvious, therefore, that preventive measures applicable to Cairo and similarly situated large towns should be directed to the destruction of the cercaria in the water taken from the Nile. The ideal, of course, would be to do away with the unfiltered supply entirely. It is said, however, that such a course would deprive Cairo of its gardens and would meet with tremendous opposition. As this unfiltered water must be a continual source of grave risk to the public health from other and more virulent diseases than bilharziosis, it is evident that such opposition must have been both strenuous and triumphant when this system of dual supply is still tolerated by the authorities. Numerous experiments were made to determine if infected water could be rapidly sterilized. The results of this inquiry will be detailed later in connection with the supply of safe water to small bodies of men. They were entirely inapplicable to the requirements of Cairo. There is, however, one feature about the bilharzia cercaria which may be used possibly to conserve the unfiltered water supply; that is the brief duration of life of the free-swimming cercaria. It has been found impossible to keep the cercaria alive for more than thirty-six hours. If it were practicable to store Cairo's daily requirement of unfiltered water for two days or a day and a half, there is no doubt that it would become practically free from danger as far as bilharziosis is concerned. It may be noted, however, that it would at the same time lose that heavy sediment which has a distinct manurial value. Against this loss may be set the fact that, under the present system, one-third of the thirty thousand children born annually in Cairo become infected with bilharzia.

ORIGIN OF BIL- The source of infection of the Nile water at
 HARZIA INFECTION IN CAIRO. Cairo is somewhat difficult to locate. Under the
 miracidium infection theory it was attributed to
 contamination of the water by infected urine from the crews on
 the boats which daily congregate near the Kasr Nil bridge. On
 the alternative hypothesis of a molluscan intermediary one must
 look farther afield. The molluscs known to harbour bilharzia
 cercaria congregate mostly in the smaller canals and ditches where
 there is a good deal of vegetable substance for food. They are air-
 breathers and require to seek the surface from time to time. In
 the Delta, water does not return to the Nile when once it has been
 used for irrigation purposes. The whole of the agricultural drainage
 water is discharged either into the salt lakes near the Mediterranean
 shore or directly into the sea. That of the valley or "Wadi Tumulat"
 which runs from Zagazig to Ismailia discharges into Lake Timsah
 on the Suez Canal. In Upper Egypt, however, the canals have
 escapes at various points on their courses which allow surplus
 water to return into the Nile. The agricultural drains also discharge
 into the Nile at certain places. These escapes are indicated on the
 accompanying map (fig. 25). It will be seen that from Minia to
 Fashn the drainage is turned sometimes into the Nile, and at other
 times into the Bahr Yusef, whence it makes its way through the
 Fayum into Lake Kurun or continues to discharge at El Ayat by
 the Giza Canal escape. Between Fashn and El Ayat all drains
 escape into the Nile, while below El Ayat the drains discharge into
 the large Moheit drain which enters the Rayah el Behera below
 the Barrage north of Cairo. A few miles south of Cairo it will
 be noticed that the Giza Canal has two escapes into the Nile.

EFFECT OF VARYING VELOCITIES OF THE THE Nile varies from month to
 CITIES OF THE Nile. Whereas the movement of water down
 NILE. Barrage occupies seven days in a mean year during
 March to August, in September the water travels the same distance
 in three days, in October and November it takes four days, while
 from December to February five days are necessary. Taking one and
 a half days as the approximate duration of life of the free-swimming
 cercaria, it is evident that at all times of the year water freshly
 contaminated with cercaria at Assiut would become safe long before
 it reached Cairo. During high flood in September the Nile has a
 velocity of about one hundred and fifty kilometres per diem, that
 is water containing freshly discharged cercaria entering the Nile
 within about one hundred and fifty miles up-stream of Cairo would

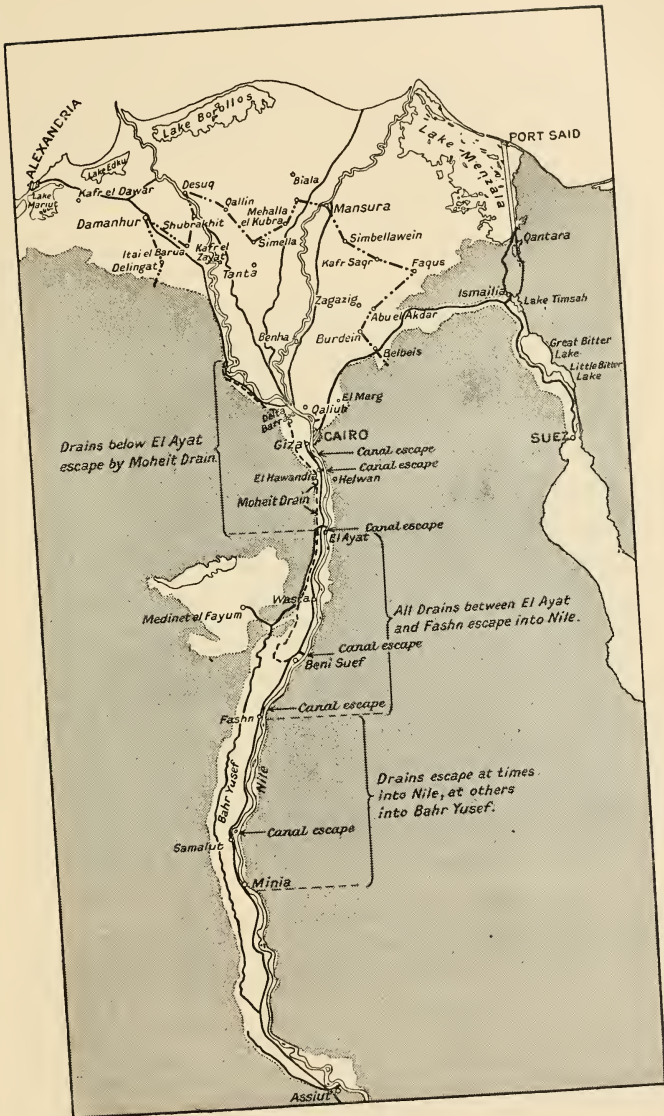


FIG. 25.

still be infective when passing the city. Minia is a little more than this distance from Cairo, so that all the drainage water which, as we have seen, discharges into the Nile between Minia and El Ayat would still be infective at Cairo during the time of high Nile. During the summer months when the Nile is at low stage the maximum velocity at Wasta (see fig. 25) varies between thirty and thirty-three kilometres per diem, according to Craig. Farther down stream this will be less as the Delta Barrage is reached, owing to decrease of slope. About thirty kilometres per day would be a fair average over this reach. According to this, active cercaria would only travel thirty miles in a day and a half, so that infected water entering the Nile more than thirty miles up-stream, i.e., above El Ayat, should have become innocuous by the time it reached Cairo except in so far as occasional infected molluscs may be carried down by the current.

If the facts upon which these conclusions are based are approximately correct, the Nile at Cairo, and therefore the unfiltered water supply, should be infective chiefly during the autumn; the source of infection during the rest of the year being apparently limited to the escapes between El Ayat and Cairo.

VELOCITIES OF THE CANALS IN THE DELTA. Down stream from Cairo, water only re-enters the Nile and the main canals by seepage. From September to December water takes 1·6 to 1·9 days to travel from the Delta Barrage to the sea. From January to April the period gradually lessens from 2·1 to 2·6 days; in May, June and July 2·8 days are occupied. From this we conclude that even during Nile flood the branches of the Nile and the main canals in the northern half of the Delta are less liable than the Nile above Cairo to be infective. The bulk of infections in the Delta must therefore originate directly from the small tertiary canals, the agricultural drains and the large drains which carry the discharge from these to the sea.

INFECTION IN THE MARITIME CANAL ZONE.

This brings us to a consideration of the Ismailia or sweet water canal carrying fresh water from the Nile north of Cairo to Ismailia, Suez and Port Said.

THE SWEET WATER CANAL. The Ismailia Canal from Cairo to Ismailia is 128 kilometres, i.e., 80 miles. From Ismailia to Suez 90 kilometres, i.e., 56 miles, from Ismailia to Qantara it is approximately 34 kilometres, and thence to Port Said about 43 kilometres. The maximum velocity on the Ismailia Canal is near

the head, about 42 kilometres per day, which probably falls somewhat lower down. On the Suez portion of the fresh-water canal at 40 kilometres from Ismailia, the velocity, according to Mr. Hall, is 0.27 metre per second—i.e., less than 24 kilometres, or 15 miles, per twenty-four hours.

Mr. Craig, of the Statistical Department, writes, that the time of flow from the Barrage to Ismailia may be taken as two days, and that this rate does not vary much from low stage to high stage



FIG. 26. —The Port Said branch of the sweet water canal at Qantara.

of the river. From this one may conclude: (a) that any infection entering the canal at its head, even during high flood, would have died out before it reached Ismailia; (b) any bilharzia infections acquired in the Canal zone from the Port Said and Suez branches of the canal must originate from local infection of molluscs in the Ismailia Canal. In the stretch from Cairo to Ismailia the canal is very free from vegetation, and molluscs are relatively very rare. From Ismailia to Qantara, and from Ismailia to Suez, the amount of weed is so great that it is difficult to traverse these sections

by motor launch. Among the weed, specimens of *Bullinus* are common. We did not succeed in finding infected forms. These two canal branches are the sole sources of supply of fresh water to Port Said and Suez. They are open to contamination with bilharzia: (1) from villages upon the banks; (2) from the pathways running the whole course of the canal; and (3) from shipping. The water appears to be infective only to a relatively small degree, because the children in the schools of Suez and Port Said show a



FIG. 27.—The sweet water canal outside Ismailia.

low percentage of cases. At Suez, one child out of nineteen in a school on the outskirts of the town was infected. At Port Said, according to Dr. Orme, bilharzia eggs were found in the urine of five out of forty healthy pupils in the Government school. At Ismailia, unfiltered water taken from the canal on the outskirts of the town is supplied to the European houses and is actually laid on as the cold water supply in the bathrooms. Had the canal water been commonly infected a considerable number of cases of bilharziosis should have been recorded among the European inhabitants.

The Port Said section of the fresh-water canal is not being used by boats and is only open to infection at the present time from those using the footpath along its bank. If this path were diverted the risk of infection should become negligible after some months. On the southern section from Ismailia to Suez a number of villages have arisen on both banks. Paths follow both banks. The canal is used regularly by small boats making forty to one hundred

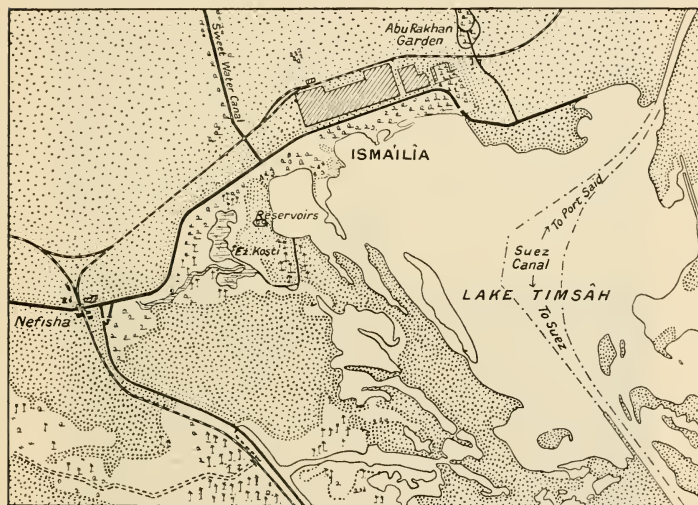


FIG. 28.—The relations of the Sweet Water Canal and its branches to the town of Ismailia.

journeys per month in each direction. From this canal water is led at intervals by small channels to the posts on the maritime canal. It appears impossible to insure under present circumstances that the water reaching these posts should be free from infection.

Local practitioners state that there is a fair amount of bilharzia amongst the native population of Ismailia. This is most probably acquired in the low-lying fields and marshes to the south-west of the town, and from the Taftish el Wady drain, which carries off the whole of the drainage of the Wady Tumulat, between Tel el Kebir and Ismailia, and ultimately debouches into Lake Timsah. Specimens

of *Planorbis boissyi* were common in the marshes and ditches there and were found harbouring developmental stages of bilharzia type.

Marshes, which usually occupy low-lying areas and derive their water in part from seepage, can only be dealt with adequately by filling. The value of the land reclaimed should compensate for this necessary outlay. Moreover, these marshes are the main breeding-places of malaria-bearing mosquitoes, and on this account

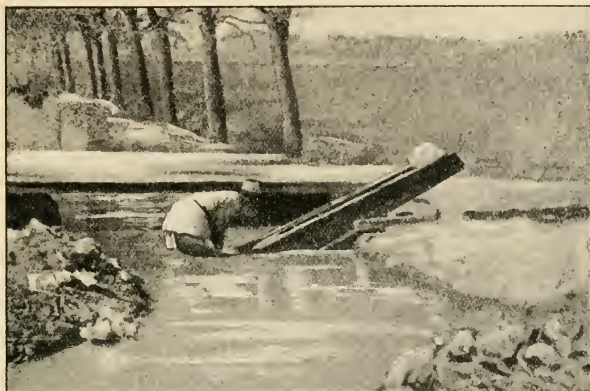


FIG. 29.—Filling marsh at Ismailia.

alone their abolition is called for even at some cost to the State, as shown in the accompanying photograph (fig. 29). The marshes near Ismailia which were found to be a possible source of danger on account of bilharziosis are being rapidly filled in as an anti-malaria measure in completion of Sir Ronald Ross' recommendations for the protection of Ismailia.

PREVENTION OF BILHARZIOSIS IN AGRICULTURAL DISTRICTS.

Whereas the essential condition to the prevention of bilharziosis in towns was found to be the destruction of the free-swimming



(From "A Textbook of Egyptian Agriculture.")

FIG. 30.—The wooden trough, "badala" or "wabor," for lifting water from twenty-five to fifty centimetres, in use.



(From "A Textbook of Egyptian Agriculture.")

FIG. 31.—The "nattala," a closely plaited straw basket with four cords, for lifting water about one metre.

cercaria, in country districts water in small canals, shallow ditches and irrigated fields is so general and there are certain agricultural appliances (such as those illustrated in fig. 30 and fig. 31) which necessitate continual exposure to infected water in such common use that other preventive measures must be found.

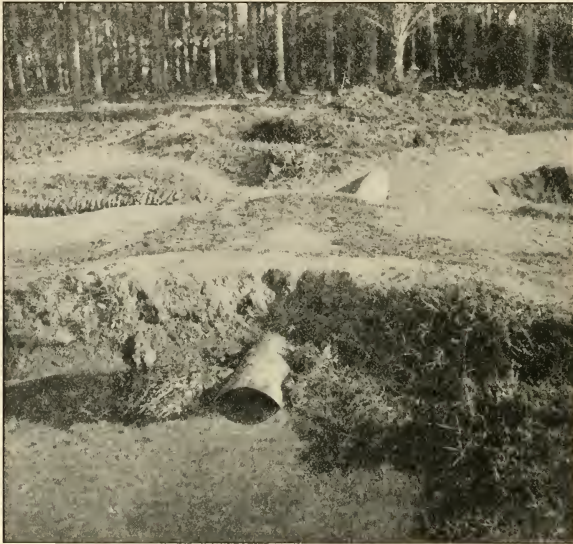


FIG. 32.—Iron pipe in the course of the Marg Canal regulating amount of flow.

GOVERNMENT CONTROL OF NILE WATER.

In those areas enjoying the privileges of perennial irrigation the water is not allowed to run indiscriminately. The supply is carefully husbanded and is entirely under the control and constant supervision of the Irrigation Department. The irrigation outlets from the public canals are furnished with iron pipes of a definite diameter so that the amount of water passing shall bear a calculated relation to the area served (fig. 32).

During the summer months the water in the canals is controlled by the periodical closure of the head regulators for definite periods. These times are officially announced by the Government. A copy

of the announcement for the earlier part of the summer of 1915 is reproduced on the page opposite. It will be seen that after running for a period of six days the water was shut off for fifteen days. This system of "rotation" was enforced at the beginning of April and was maintained until the Nile flood (as shown in fig. 23) reached the Delta early in August.

Under the Canal Act of 1894 severe penalties are imposed upon those attempting to interfere in any way with the working of the irrigation system. Imprisonment for periods up to two months and fines not exceeding £20 may be imposed in cases of infraction or disregard of the law.

With the increase in the amount of water available which has followed upon the building of the various dams and reservoirs, new lands more remote from the Nile have annually been brought under cultivation.

SUGGESTIONS FOR ERADICATION.

If some simple means could be found of stamping out the molluscs in those situations in which the molluscs harbouring bilharzia congregate and multiply not only would the incidence of the disease be greatly reduced in the country, but the liability to infection would also be greatly diminished in the large towns, e.g., Bilbeis, on the main drains into which the small drainage ditches discharge. The following proposals are based upon a study of

the problem in the district of which Marg is the centre. The method, which seems applicable to other parts of Lower Egypt, save, perhaps, those in which rice is the chief crop during the summer months, utilizes the present "rotations" in the supply of water enforced by the Government from April until August. During periodical stoppages of fifteen days the El Marg Canal became dry except for occasional puddles (figs. 11, 12, 33, 34, 35). The molluscs were either stranded upon the drying mud or collected in these puddles. It was found that several days before the return of the water the *Planorbis* and *Bullinus* taken from the dry bottom did not revive when placed in water. Those in the small puddles of water had been able to survive, the *Planorbis* being apparently more hardy than the *Bullinus*. Had any attention been given to the alignment of the Marg Canal so that small collections of residual water could not provide a "carry-over" for the molluscs, these would have been killed automatically by the "rotation" alone, just at the commencement of their annual reproductive activity. The same

[Copy.]

MINISTRY OF PUBLIC WORKS.

IRRIGATION DEPARTMENT—FIRST CIRCLE.

PROGRAMME OF SUMMER ROTATIONS, 1915, IN QALIBIA, SHARQIA, AND DAQHUIA PROVINCES.
Canals on Cotton Rotations.

The following are the sections into which the various canals are divided for rotation purposes :—

Names of Canals	LIMITS OF SECTIONS					
	Section A		Section B		Section C	
	From	To	From	To	From	To
Isma'ilia branches	Head	Qalibia boundary	—	—	—	—
Sharqawia	Head	Khalili Head	—	—	—	—
Sissa	"	Tail	—	—	—	—
Marsafawia	"	"	—	—	—	—
Qenneba and branches	"	"	—	—	—	—
Khalili and branches	—	—	Head	Tail	—	—
Zefaita and branches	—	—	—	—	Head	Tail
Shebini and branches	—	—	—	—	"	"

SUMMER ROTATIONS (1915) IN LOWER EGYPT.

Summer Rotations, in accordance with the lists already published for each Circle of Irrigation, will be imposed throughout Lower Egypt as per the time-tables given below :—

Canals on Cotton Rotations.

	PERIOD		SECTIONS		
	From	To	A	B	C
	April 8	April 13	Stopping	Working	Stopping
	" 14	" 19	Stopping	Stopping	Working
21 days	April 21	April 20	Working	General stopping	Stopping
	" 28	April 27	Stopping	Stopping	Working
	May 5	May 4	Stopping	General stopping	Working
	" 12	May 11	Working	Stopping	Working
21 days	May 19	May 18	Stopping	General stopping	Stopping
	" 26	May 25	Stopping	Working	Working
	" 26	May 31	Stopping	General stopping	Working

REMARKS.

(1) *Séf* channels not specifically named in this list will be on the same rotation as the parent channel from which they derive their supply.

(2) The working turn, or period over which irrigation is allowed, begins at sunrise of the first day of the period and ends at sunrise of the day following the last day of the period.

(3) During the working turn of any section, water will be supplied, to the extent that the available supply of water may permit, to all public and private canals and outlets lying within the limits of that section, as described in the programme.

(4) The heads of all private canals and all outlets must be punctually closed and all lifting machines must cease to work at the expiration of the working turn.

(5) By Article 32 (30) of the Canal Act, 1894, it is enacted :—

"Whoever takes water from a canal, whether by opening the head of the canal, or of the water-course, or by cutting banks, or by lifting the water artificially during the days that the Inspector of Irrigation or any other authority duly authorized shall have made known that water from the canal must not be used for irrigation, will be punished by imprisonment for a period of from fifteen days to two months, and a fine not exceeding L.E.20.

(6) The prescriptions of Article 32 (30) of the Canal Act will be strictly enforced, and the Irrigation Service will take such further administrative measures in case of infraction or disregard of the Law as the nature of the case may require.

(7) The breakdown of a lifting machine gives no right to compensation-supply out of turn.

object might be attained by the provision of an alternative route for the "rotation" water from the secondary canal to the fields.

CHEMICAL
AGENTS.

The small collections of residual water might be treated chemically so as to destroy the surviving molluscs. As the water so treated would be carried on to the land at the commencement of the following "rotation" it would be essential that the chemical used should not be injurious



FIG. 33.—The bed of the Marg Canal in the village during a summer rotation.

to the crops. Certain chemicals are used nowadays on a large scale as manures. It was found experimentally that some of these, especially ammonium sulphate, in weak solution killed the molluscs within a few hours. This chemical manure can therefore be used with safety, and *without ultimate loss*, to kill off those molluscs which had escaped destruction by drying.

CLOSED
DRAINS.

The small drains, such as that figured on page 39, are less cared for, as a rule, than the small supply canals. They consequently become over-grown

with weeds, which frequently afford sufficient protection to the molluscs to enable them to survive for a considerable period. In Egypt, drainage is always effected by means of open drains. The periodical clearing of these drains must, therefore, be regarded as an essential part of any scheme for the eradication of bilharziosis until the open drain can be abolished.

The English system of field drainage by underground pipes has scarcely received proper trial in Egypt. Quite recently the State Domains Administration made some experiments on the washing of salted land by filtration into drain pipes and this method was found to be better than that of filtration into open drains. The cost, however, proved out of proportion to the extra benefit from the agriculturists' point of view.

Although the initial cost may seem considerable, it should not be overlooked that there would be a distinct saving in other directions. The annual charges for clearing the open drains would be abolished, there would be no heavy losses or damage through the falling of live stock into the drains, and the land recovered would represent a considerable increment of capital.

Lang-Anderson has estimated that if pipes could be obtained in Egypt at about the same cost as prevails in England, the conversion of an open drain 300 metres in length into a covered drain would involve an outlay of a little over £3. About 1,200 square metres of land previously occupied by the open drain would then be available for agricultural purposes. Valued at £42 per feddan, this recovered land would be worth £12.

The mole drain plough is said to be an efficient and very cheap method of drainage. Lang-Anderson believes that the soil of Egypt would give a satisfactory bore to this machine. If this proved to be the case earthenware pipes could be dispensed with.

The canals are closed annually for a period of a month, usually from December 25 to January 25, to allow of the removal of silt. If it were practicable to carry out these canal clearances at the commencement of the summer in conjunction with the rotations of water, the work should greatly assist in the elimination of the fresh-water molluscs.

As the anti-bilharziosis measures proposed depend for their success upon the summer rotations, the campaign would be confined to the months from April to August. We now proceed to acquaint ourselves with the agricultural activities in perennially irrigated land during these months, to see to what extent these would assist or

CANAL
CLEARANCES.

A SUMMER
CAMPAIGN.



FIG. 34.—Marg Canal as it enters the village, a few days after the water has been cut off in the “rotations.”



FIG. 35.—Marg Canal passing the railway station, same view as in fig. 5, but during the “rotations.”

interfere with the steps proposed. The main crops in Egypt are cotton, wheat, clover, and maize. Wheat and clover are winter and spring crops, and are harvested by May. Cotton occupies the land from April until October. Maize is a "catch" crop, sown late in July and harvested in October. Apparently the chief crop under cultivation during June and July is cotton. Cotton is not grown annually. On the best land it can be grown every alternate summer, but it is usually planted once in three years on the same land.

DATES OF SOWING AND HARVESTING IN LOWER EGYPT.

<i>Sowing.</i>		<i>Harvesting.</i>	
March to April	.. Cotton. Lucerne. Earthnuts. Henna. Onions. Summer melons. Sugar-cane.	March to April	.. Flax.
May to June	.. Summer rice.	April	.. .. Fenugreek and lupins.
June to July	.. Sesame.	April to May	.. Barley.
July to August	.. Flood melons. Maize. Millet. Flood rice.	May	.. .. Wheat.
Sept. to Nov.	.. Berseem (clover).	June	.. .. Seed berseem.
Oct. to Nov.	.. Lupins. Flax.	July	.. .. Onions.
Nov. to Dec.	.. Wheat. Barley. Beans.	July to August	.. Summer melons.
		Sept. to Nov.	.. Summer rice. Dates—cotton.
		Sept. to Dec.	.. Henna.
		Oct. to Nov.	.. Maize. Sesame. Melons.
		Nov. to Dec.	.. Maize. Millet. Earthnuts.
		Nov. to March	.. Sugar-cane.
		Nov. to May	.. Green berseem.

On the simple three years' rotation usual in Egypt the land is divided into three parts, and placed under wheat, clover, and cotton. Wheat and clover being winter crops are harvested before June, and the land is left in bare fallow until the following February, unless a catch crop of maize is interposed at the beginning of August. We see from this that at the present time two-thirds of the land is annually in bare fallow during June and July, while the remaining third is under cotton.

Turning now to fig. 36, it will be observed that May, June and July are the months in which humidity reaches its lowest point, and the temperature attains its maximum, consequently evaporation is most rapid at this time. The climatic and agricultural conditions in Egypt are therefore most favourable for a campaign against the

	FIRST YEAR		SECOND YEAR		THIRD YEAR	
	Winter	Summer	Winter	Summer	Winter	Summer
Average						
One-third	Wheat	Bare fallow	Clover ("Catch" crop)	Cotton	Clover	Bare fallow or Maize ("Catch" crop)
One-third	Clover	or Maize ("Catch" crop)	Wheat	Bare fallow	Clover ("Catch" crop)	Cotton
One-third	Clover ("Catch" crop)	Cotton	Clover	or Maize ("Catch" crop)	Wheat	Bare fallow or Maize ("Catch" crop)

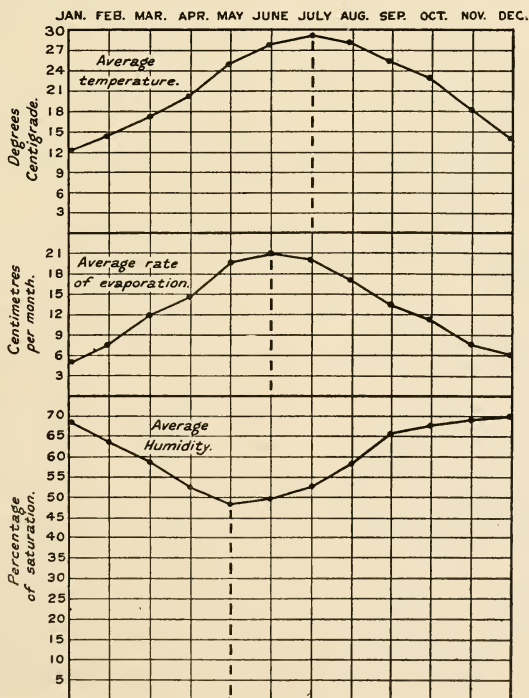


Fig. 36.—Monthly average temperature, humidity and evaporation.

molluscan carriers of Bilharzia during June and July. Taking tertiary canals as supply units, it should be possible by adjusting the rotation of crops so to group the land under cotton that, in a given area, a third only of the tertiary canals need be used during these months. The tertiary canals and drains supplying the other two-thirds of the land would become thoroughly desiccated, and their molluscan fauna completely destroyed.

If the additional precaution of screening the tertiary canal head were taken, the diminished supply involved by the mesh should be compensated for by the insertion of a second screened pipe rather than by the replacement of the original pipe by one of larger bore. The screens would require periodical cleaning and supervision throughout the year.

UTILIZING LEAN YEARS. The table of charaki lands given on p. 53 shows in feddans that a large area, varying from year to year, is thrown out of cultivation when there is a shortage of Nile water during the summer. Further, the Government, under circumstances like those operating during the present War, takes steps to restrict the area placed under cotton. Whenever the land is brought into bare fallow from such causes, efforts should be made as far as possible so to group the incidence of fallow and cotton fields in a given area that the transient financial loss directly contributes to a diminution in the amount of Bilharziosis in the district penalized.

BILHARZIOSIS CAMPAIGN AND COTTON WORM. The proposal to render cultivated land as dry and hot as possible during the whole of June and July as a means of attacking the bilharzia-carrying molluscs would be very beneficial for the cotton fields themselves. The prominence of Egyptian cotton in the world's market is based upon its quality alone, and it has been shown that considerable deterioration follows a too copious supply of water. Moreover, when green and well-irrigated fields of clover are interspersed between the cotton fields during June, the cotton worms are provided with plenty of food and shade until the young cotton plants have produced sufficient foliage to receive them. If, on the other hand, the cotton fields can be kept dry, and the plants consequently hard and fibrous, millions of the cotton worms would perish.

ROADS AND SHIPPING. The contamination of the water with infected urine and fæces must continue so long as the river and main canals are the chief vehicle for transport in Egypt. There are still few main roads, and these generally

occupy the banks of canals and main drains which are entirely open to pollution. At the present day, as in the time of Herodotus, "The Egyptians perform publicly those natural functions which it is the custom for members of other races to carry out in private." In the new areas now being reclaimed, it should be possible to provide more adequate protection for the main watercourses.

The replacement of the small agricultural drains by piping or by "mole" drains, together with the proper utilization of canal clearances and the periodical drying of the small canals during the summer "rotations," should prove successful in controlling bilharzia, even although the molluscan intermediaries were not entirely destroyed. The molluscs are slow in growth and propagation as compared with other animal carriers of human diseases. Re-stocking with half-grown or adult forms might be prevented if it proved practicable to screen the iron pipe regulating the flow of a tertiary canal at its head.

CONCERNING RECLAMATION.

At the beginning of the nineteenth century, owing to neglect, the cultivated area of the Delta had shrunk to that portion lying between Cairo and an irregular line (shown on fig. 25) passing through Delingat, Damanhur, Itai el Barua, Shubrakhit, Desuq, Qallin, Simella, Mansura, Faqus, Burdein, and Bilbeis. The introduction of perennial irrigation brought about a rapid increase in the population of Egypt, which was met by an extension of the area brought under irrigation. This increase still continues and is greatest where irrigation projects are most active. During the ten years ending 1907 the population, according to Willcocks, had increased sixteen per cent, while the cultivated area increased only thirteen per cent. It is clear, therefore, that new land must be brought continually under cultivation to meet the increasing needs. The total acreage of Lower Egypt is 5,190,000 acres. Of this, 3,100,000 acres are now cultivated land, 1,190,000 acres are waste land ("Berea"), or ordinarily too salted to produce crops without reclamation; 600,000 acres are covered by lakes. The whole of the Berea or waste land was cultivated in the Ptolemaic and Roman era. According to local tradition some of these waste tracts now bordering the lakes were once covered with vineyards or divided into enormous basins planted with wheat. The numberless mounds strewn with bricks and pottery which nowadays arise from these extensive barren plains are evidence that they once supported a dense population.

As we have seen (p. 52) the extension of perennial irrigation in the past has been accompanied by a similar extension of bilharzia infection. The bilharzia-carrying fresh-water molluscs cannot live in saltish water. Every effort should be made, therefore, in the future reclamation of the salted lands in the north of the Delta to ensure, as far as possible, that favourable conditions are not created at the same time for their colonization by the bilharzia-spreading molluscs.

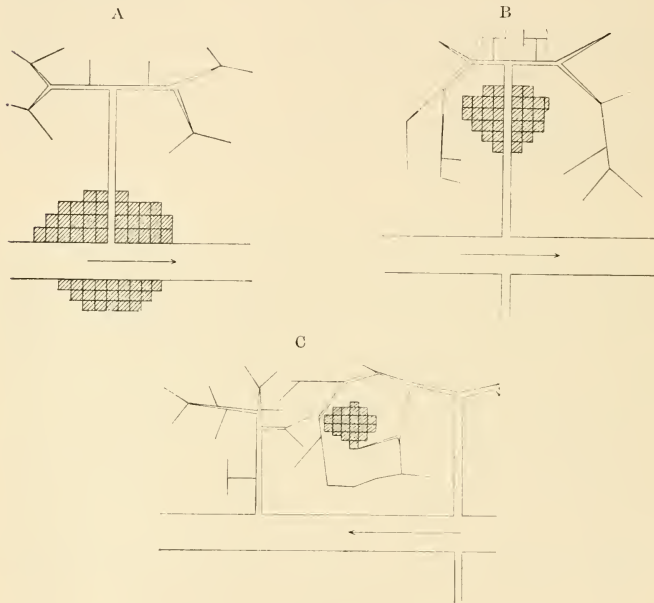


FIG. 37.—The relations of villages to the canals. A, village on either bank of a main or secondary canal; B, village on a tertiary canal; C, village between two tertiary canals.

(1) If the banks of main canals or drains are used as roads the water should be adequately protected from contamination. If possible, however, the roads should run between the terminations of two systems of tertiary drains.

(2) Villages should not be made on the main drains or on the primary or secondary canals. They should be located as far as

possible between two tertiary canals. A glance at fig. 37, A shows at once that where a village is on the bank of a main or secondary canal the bilharzia eggs and embryos carried on in the main stream passing through the village are liable to infect all the tertiary canals supplied from the canal in the section down stream of the village. This arrangement one sees frequently on the Suez section of the sweet water canal. Where the village is on a tertiary canal (fig. 37, B) as happens at El Marg, the water passing through the village is dissipated on the surrounding fields so that the area of infectivity of the village is limited practically by its own communal boundaries. Where a village lies between two tertiary channels, as in fig. 37, C, the liability to contamination of the water channels is practically restricted to those paths leading from the village and such branches as are used for washing and other domestic purposes.

(3) The village water supply should be derived from "sakias" or deeper wells. Each irrigation unit should possess paired supply canals and drains, so that these may be alternately dried without interfering with the irrigation. At Marg, when the canals became practically dry during the rotations, a certain amount of water was drawn from a sakia in the middle of the village. On one occasion when the shortage was becoming serious, a neighbouring land proprietor diverted a generous supply of clear artesian water into the Marg Canal. This, however, revived enormous numbers of molluscs which otherwise would, undoubtedly, have been killed by drying before the completion of the rotation cycle!

(4) Surface-water drains should be reduced, as far as possible, by the utilization of infiltration drains.

The Mosséri system of field drainage, which is said to be simple, economical, and extraordinarily effective, seems, of the various systems of land reclamation at present in use, to be the one most likely to produce those conditions that are unfavourable to the spread of bilharziosis.

Its dual system of "collecting" drains affords more complete control. From the section shown in fig. 39, it will be apparent that the bulk of the surface water, after irrigating the land, rapidly drains by a separate surface drain into the main drain, while the water which has soaked into the soil is drawn off by a deep infiltration drain to be pumped later into the main drain. The surface water drain can therefore be readily sterilized during the summer by drying, while if need be, the deep infiltration drain can be treated with chemical agents, or periodically cleared.

If a campaign against bilharziosis were commenced on the lines here proposed it is evident that the whole scheme should be under the charge of a medical zoologist, who should be attached, not solely to the Public ADMINISTRATIVE.

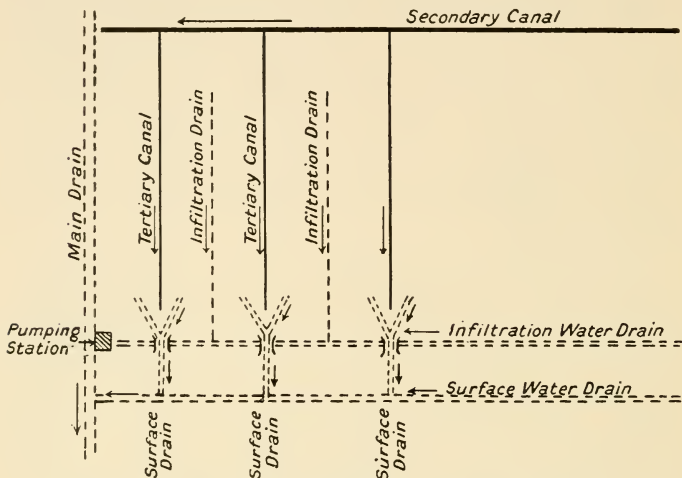


FIG. 38.—The Mosséri system of drainage. (After Willcocks and Craig.)

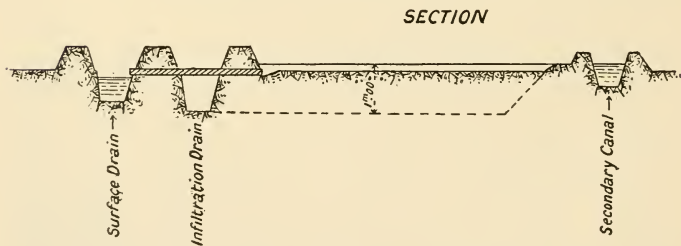


FIG. 39.—Section showing relation of infiltration and surface drainage in the Mosséri system. (After Willcocks and Craig.)

Health Service as in an ankylostomiasis campaign, but also to the Department of Irrigation. In this way only could the full and continuous effect of the present administrative control of the Nile

water be brought to bear upon the bilharzia-carrying molluscs so as to ensure their permanent eradication from lands now heavily infected and their exclusion from new areas about to be reclaimed.

PROTECTION OF TROOPS AND PERSONAL PROPHYLAXIS.

Having dealt with the mode of transmission and suggested the lines upon which eradication might be effected in the course of a few years if undertaken by the State, we come now to consider the preventive measures that should be adopted by the individual, or collections of individuals, working in districts where the disease is still rife. It is obvious from what has been said on p. 47 (Part I), that in large towns where filtered water is supplied both for drinking and bathing there is practically no risk to the European. A study of the bionomics of the cercaria gives the data wherewith unfiltered water can be rendered safe where filtered water is unavailable or insufficient for all personal purposes.

BIONOMICS OF BILHARZIA CERCARIÆ.

ACTIVITY. The bilharzia cercariæ move by louping and by swimming. They crawl rapidly over any surface by alternate use of the oral and ventral suckers, the tail being dragged behind passively. When swimming the tail and the whole body gyrates and the cercaria progresses with the pronged tail foremost. Swimming is not continuous. Brief periods of activity are regularly alternated with periods of rest. During these latter the cercaria very slowly sinks. When seen with a hand lens their attitudes recall slightly minute mosquito larvæ. As a rule they frequent the surface, but when a small mammal like a mouse is placed in the water they at once attack the skin. As successful infection resulted in a young mouse after only ten minutes' immersion on a single occasion they appear to be able to pierce the skin very rapidly.

DURATION OF LIFE. In ordinary tap-water freshly discharged cercariæ usually live about twenty-four hours. A considerable number survive thirty-six hours, but none has ever been found alive after forty-eight hours. They are apparently unable to obtain nourishment from water. An infected mollusc will apparently continue to discharge active cercariæ for a long period. On two occasions infected *Planorbis boissyi* were kept in tap-water, which was renewed daily for three weeks. Large numbers of cercariæ were discharged into the water every day.

EFFECT OF DRYING. The cercariæ can survive on a damp surface from which the visible water has disappeared. They are immediately killed if the drying process is allowed to proceed to the extent of abstracting fluid from their bodies. They cannot withstand the slightest desiccation.

NEED OF OXYGEN. Although the bilharzia cercariæ, with one exception, are not provided with eye-spots, the bulk are found near the surface of the water. They accumulate there irrespective of exposure to light. If a thin layer of oil or refined paraffin is poured on to the surface of the water the length of life of the cercariæ is reduced to a few hours. This may also be observed when a drop of water containing cercariæ is periodically examined under a sealed cover-glass. If a bubble of air has been left in the preparation it will be noticed that the cercariæ course round and round its circumference like moths around a flame.

The obvious purpose is to obtain oxygen from those portions of the water nearest the air.

EFFECT OF TEMPERATURE. The free-swimming bilharzia cercariæ can survive a temperature of 45° C. They are killed, however, when the temperature is momentarily raised to 50° C. This corresponds very closely to the clinical finds of Conor [116] in Tunis. He noted that bilharziosis is acquired from the waters of the thermal springs at Gafsa, Tozeur and Gabès, which have a temperature of from 28° C. to 45° C., while the disease was quite absent in the neighbourhood of other springs in Tunis where the temperature ranges from 50° C. to 70° C.

EFFECT OF CHEMICAL REAGENTS. Very weak alkalies were found to have a stimulant action and weak acids an inhibitory effect on the movements of the bilharzia cercariæ. One in five hundred hydrochloric acid kills immediately. The following acids, acid salts, essential oils and antiseptics were found in dilute solutions of varying strengths to have a lethal effect on the cercariæ:—

Salicylic acid	..	..	1 in 1,000	..	Kills at once.
			1 in 2,000	..	Slight movement after 50 minutes.
Benzoic acid	..	..	1 in 2,000	..	Kills at once.
Sodium bi-sulphate	..	..	1 in 1,000	..	Kills almost immediately.
Oil of cloves	..	..	1 in 1,000	..	Kills in 10 minutes.
Creosote	..	..	1 in 1,000	..	Immediate paralysis; slight movement of tail.
Felix mas	..	..	1 in 5,000	..	Kills in 15 minutes.
Chinosol	..	..	1 in 1,000	..	Immediate effect; slight movement.
			1 in 5,000	..	All dead in 4 hours.

Cresol	1 in 10,000	..	All dead in 5 minutes.
Microcidine	1 in 10,000	..	All dead in 20 minutes.
	1 in 20,000	..	Dead in 50 minutes.
	1 in 40,000	..	Dead in 2 hours 50 minutes.
Beta-naphthol	1 in 1,000	..	Kills immediately.
	1 in 10,000	..	Stopped swimming immediately.
	1 in 100,000	..	Fibrillar twitching and wriggling in 1½ hours; motionless in 2 hours.
	1 in 200,000	..	Swimming stopped in 1 hour; quite motionless in 2 hours.
Emetin	1 in 2,000	..	Dead in 30 minutes.
	1 in 10,000	..	Slight contraction at 50 minutes; dead in 3½ hours.
Thymol	1 in 1,000	..	Kills immediately.
	1 in 10,000	..	All movement stopped in ¼ hour; dead in ¾ hour.
	1 in 20,000	..	Swimming stopped in 2 minutes; some creeping.
Fresh chlorinated lime ..	1 in 40,000	..	Body disintegrated in 1 hour.
	1 in 30,000	..	Kills at once.
	1 in 50,000	..	Dead in 3 minutes.
	1 in 300,000	..	Actively swimming after 1¼ hours.
Sodium hydroxide	1 in 500,000	..	Active after 2¼ hours.
	1 in 1,000	..	Immediate immobilization.
Chloroform water	1 in 5,000	..	Actively swimming after 2 hours.
	1 in 1,000	..	Paralyzes swimming; ineffective creeping movements. On addition of water swimming regained in 5 minutes.

EFFECT OF TEMPERATURE ON METAMORPHOSIS. Many trematodes undergo their larval metamorphosis in molluscs during certain months of the year. Looss [290] remarked that in Egypt when the temperature falls in winter to about 5° to 6° C. the growth and multiplication of larval trematodes is sometimes wholly suspended, while in Central Europe it is only retarded at this temperature. Autumn seemed to be the most favourable period for fresh infections of intermediate hosts. During winter young parasites develop little but only reach the stage of cercarial production in the warm season. The appended table shows the monthly variations in the temperature of water near Cairo.

During February we found sporocysts containing secondary sporocysts and bifid-tailed cercariæ in *Planorbis marcoticus*. In March eyed bilharzia cercariæ were found also in this species. Non-eyed bilharzia cercariæ were first detected in *P. boissyi* on April 17 and in *Bullinus* on June 8. Once located, the cercariæ were obtainable throughout the entire year, but were very scarce from January to March. It would appear, therefore, that infection is by no means confined to the autumn as has been generally supposed.

PENETRATION. Free swimming cercariæ could not be recovered from infected waters, as they pass through the finest silk mesh. They readily pass through stocking material, and,

given time, will succeed in traversing several inches of sand if there is a continuous flow of water through it. Unlike the ankylostome larvæ, they are unable to traverse ordinary filter-paper.

TEMPERATURE OF NILE WATER AT HAWAMDIA, NEAR CAIRO.

	6 a.m. (deg. C.)		4 p.m. (deg. C.)	
January	14.2	..	..	14.8
February	10.3	..	..	12.9
March	16.1	..	..	16.1—18.6
April	20	..	..	21.8
May	22.4	..	..	24.4
June	25.7	..	..	27.4
July	26.7	..	..	28.1
August	26.8	..	..	27.8
September	25.5	..	..	26.5
October	25	..	..	25.5
November	21.9	..	..	21.9
December	16.8	..	..	17

(From "The Physiography of the Nile," by G. H. Lyons.)

WATER
FILTRATION

In the spring of 1916 further experiments were made at the request of Surgeon-General Sir W. Babbie to determine the degree of protection afforded by a modified Jewell system of filtration which it was proposed to instal at various points on the Sweet-water Canal. This system consists in the addition of alum in a settling tank prior to filtration through sand about a metre in depth, and provides for six possible traps for the *Bilharzia cercariæ* during the passage from the source to the consumer, viz. :—

- | | |
|--------------------------------|---|
| (a) In the settling tank | (1) Time factor. |
| | (2) Exposure to oxygen. |
| | (3) Chemical action of alum. |
| | (4) Arrest from entanglement in the flocculent precipitate. |
| (b) In the filter | (5) Arrest on the surface by the "vital layer." |
| | (6) Arrest due to depth of sand. |

A working model was kindly supplied by Mr. McCroquidale, manager of the Cairo Waterworks, and the rate of flow, head of water and depth of sand were identical with those adopted for the field systems, the only difference being in the superficial area of filter and settling tank.

The following conclusions were formulated :—

(1) The *B. cercariæ* survive and remain actively swimming for a much longer period than the time (five to eight hours) that the water takes to pass through the settling tank.

(2) Oxygen has a stimulating effect on the cercariæ and is a necessity for their continued activity.

(3) Alum in the dilutions used for sedimentation of canal water has no effect on the *B. cercariæ*.

(4) The *B. cercariæ* are not entangled in the flocculent alum precipitate. They are seen swimming freely in the supernatant fluid twelve hours after the addition of the alum.

(5) The "vital" layer, formed by the deposition of alum on the surface of the sand and the arrest of bacteria and fungi therein, does not arrest the *B. cercariæ*. These were found to pass easily through the layer formed by the passage for half an hour of aluminized water taken from the settling tanks of the Cairo Waterworks. The same result followed in another test made by passing newly forming alum precipitate on a small area of sand for an hour, thus producing an abnormally thick layer. This too offered no obstacle to the leech-like progression of the cercariæ, for they were found actively swimming in the filtrate twenty-four hours later.

(6) Finally, depth of sand presented no insuperable barrier, for very active cercariæ were found in the filtrate of our working model within one hour after their addition to the inflow of aluminized water, a depth of thirty inches of sand having been traversed in this interval. The sand was a sample of that ordinarily used by the Cairo Waterworks. Sand of the finest grain used in filtration was similarly tested and proved inefficient.

Mechanical systems of filtration, such as the Jewell system, depend therefore solely on the delay they interpose between the discharging mollusc and the consumer for the amount of protection they afford against bilharziosis. At Cairo the additional delay after the intake of water from the main stream of the Nile is about twelve hours, while at Ismailia under a different system the delay is about twenty-four hours. The uniform dispersal of the cercariæ in the filtered water has also to be borne in mind. The "time factor" in the life of the *B. cercariæ* apparently affords a satisfactory explanation of the relative immunity of Europeans in those Egyptian towns where there is both a filtered and raw water supply.

CHEMICAL
STERILIZATION.

(A) Sodium bisulphate is used in "tabloid" form to sterilize water for drinking purposes. Two "tabloids" are dissolved in a quart water-bottle as a rule. Each "tabloid" contains 16 gr. (1 grm.). This gives a dilution of 1 in 567. In a previous paragraph it was shown that a dilution of 1 in 1,000 was quickly lethal to the bilharzia cercaria. These "tabloids" may therefore be used with safety in bilharzia-infected countries.

(B) In view of its germicidal value, chlorine 1 in 1,000,000 acting for half an hour, is in common use. From the tabulated effects of chemical reagents on the cercaria it will be seen that this dilution

would not have the requisite effect upon the activity of the bilharzia cercaria. It would be necessary to use two parts of available chlorine per 1,000,000, and afterwards to dechlorinate in order to render water taken from the canals and ditches in Egypt free from bilharzia infection.

For troops stationed on small outposts in the Delta safe water can be had, after two days, by improvising storage in tarpaulin sheets, etc. Where this is impossible the drinking water should be separated from ablution water and the former sterilized by boiling or by tablets of acid sulphate of soda. *The ablution water may be rendered quite safe for immediate use by the addition of ordinary Army "Cresol" in the dilution 1 in 10,000, while 1 in 90,000 is sufficient if the water is kept overnight.*

PRACTICAL CONCLUSIONS.

From the above it may be concluded that unfiltered water taken from canals, ditches, or birkets would be rendered safe:—

(1) If kept beyond the survival period of the cercaria, i.e., for forty-eight hours.

(2) If heated to 50° C., a temperature at which the cercaria is immediately killed.

(3) If previously treated with those chemicals that are lethal to the cercaria.

Attention should be given to the following points:—

(1) Personal contact of any kind with unfiltered water is risky. The surface of the water is the most likely to be infective as the cercariae congregate there. Canal water should not be "dipped" for, but should be drawn by hand pump. An intake pipe should always be led to the centre of the stream and should draw the water from near the bottom and at a place where there is little or no vegetation.

(2) It is essential in drawing water for storage, in order to destroy the bilharzia cercaria, that no infective mollusc be admitted. This can be ensured by screening the intake pipe with gauze having about six meshes to the linear inch. The common mosquito gauze or phosphor-bronze wire gauze is very serviceable.

(3) The water in the wells with "sakias" may be regarded as much safer than that from other sources. Hitherto molluscs have not been found in these wells.

(4) Shallow barrel sand-filters afford no protection.

(5) Although the reproductive activity of bilharzia in the molluscs is most intense during the summer months there is a certain liability to the infection throughout the year.

PART III.
DEVELOPMENT.

DEVELOPMENT IN INTERMEDIARY.

THE reproduction of digenetic trematodes takes HETEROGONY. the form known as heterogenesis or heterogony, of which the chief features are : (a) an alternation in the modes of reproduction, an asexual phase alternating with a sexual phase ; (b) the asexual individuals differ in shape and in internal structure from the sexual forms ; (c) the two kinds of reproducing individuals live under conditions which are more or less radically different. All digenetic trematodes have their asexual phase in the mollusca, and for the most part in the gastropoda. The sexual phase is attained in a vertebrate. The asexual phase has one or more generations. The egg on hatching gives rise to a ciliated larva, the "miracidium," which dies in about twenty-four hours unless it has been able to harbour in a suitable mollusc. Within this mollusc the miracidium,

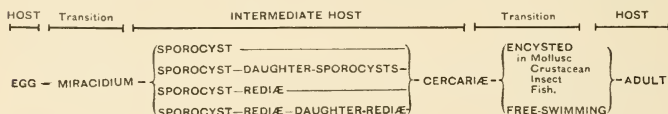


FIG. 40.—Life-cycle of a digenetic trematode.

usually after migrating to the digestive gland or "liver," becomes changed into a smooth-walled sac called a sporocyst. Budding from the wall of the sporocyst results in bodies which may be of three kinds: (a) cercariæ ; (b) daughter-sporocysts ; (c) rediæ. The cercariæ are typically immature adults provided with certain larval structures to enable them the better to invade the definitive host. They are the infective forms.

The daughter-sporocysts are elongated sacs resembling the mother-cysts, and are not provided with alimentary canal or suckers. They migrate from the mother-cyst to other parts of the digestive gland, and later give rise by budding to cercariæ.

Rediæ are characterized by the presence of a single sucker and a simple sac-like alimentary canal. These give rise by internal

budding (*a*) to cercariae, or (*b*) to other rediæ which ultimately give a brood of cercariae.

These four lines of development which may be taken by a digenetic trematode are graphically tabulated in fig. 40.

From the account already given of the experimental production of adult *Bilharzia* worms after submission of a suitable definitive



FIG. 41. -A sporocyst from *Planorbis* containing daughter-sporocysts. On the right is a free daughter-sporocyst.



FIG. 42.—Daughter-sporocysts teased from Liver.

host to infection by cercariae, it was evident that *bilharzia* development probably followed one or other of these alternative courses. In fact, the *Bilharzia* worms are typical digenetic trematodes, and conform to the second type of development in the intermediary host.

The *Bilharzia* miracidium gives rise to a sporocyst, which in turn produces daughter-sporocysts (fig. 42).

After leaving the mother-cyst, the daughter-sporocysts migrate into the tissue of the hepatic gland and grow rapidly. They become greatly elongated and eventually ramify throughout the organ, so increasing its bulk that an infected mollusc can be detected at a glance. The colour also of the organ is changed. In *Bullinus* and *Planorbis* the gland is brown or dark green, but when infected this changes to ochre.

The ends of the daughter-sporocysts are solid, but the walls of the tubular bodies are very delicate and transparent, so delicate that it is impossible to dissect a complete sporocyst free from the

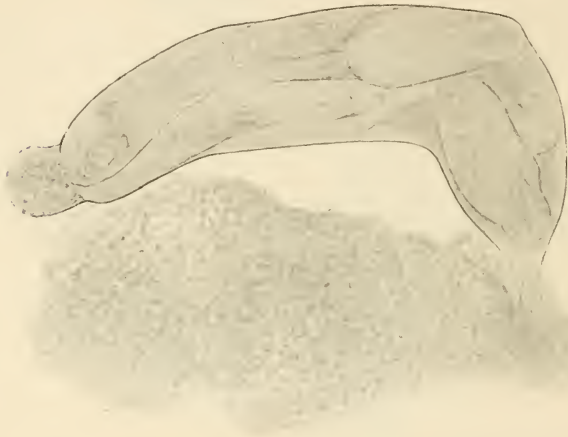


FIG. 43.—Terminal portion of a daughter-sporocyst containing fully developed cercariae.

tissues. As the cercariae develop within them, the sporocysts may become markedly constricted by the host tissue (fig. 44), and a certain amount of multiplication may possibly occur through scission. These sporocysts appear to absorb their nutriment through their walls, as they have neither oral sucker nor alimentary canal. The glandular tissue of an infected organ disappears apparently through pressure atrophy (fig. 44). The sporocysts are capable of travelling by wriggling movements. The cercariae leave the sporocysts through simple rupture of the over-distended wall. They are discharged from the mollusc in "puffs," a number being periodically shot into

the water. This discharge occurs quite independently of the passage of fæces by the snail.

In *Bilharzia* as in all digenetic trematodes the terminal phase of development in the intermediate host is the cercaria, and this alone is the infective stage.

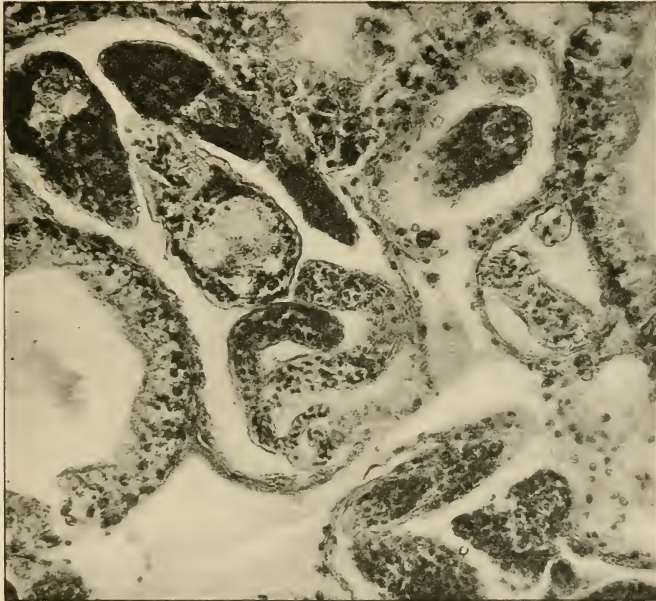


FIG. 44.—Section of hepatic gland of infected *Planorbis boissyi*, showing extent of atrophy of tissue.

DIFFERENTIATION OF CERCARIE.

A cercaria consists typically of two parts, viz., body and tail. The tail is always discarded when the body enters its final or definitive host. It is therefore a purely larval structure. The body, on the other hand, is actually the undeveloped adult, many of the adult characters being almost undifferentiated. In addition to these the cercarial body may have other structures which have been serviceable during its growth in the molluscan host, but which

are absorbed and entirely disappear after the final host has been reached. There are, then, in every cercaria "adult" characters and "larval" characters, the former being chiefly exhibited by the digestive, excretory and genital systems and by the oral and ventral suckers, the latter by the tail and by the armature of the skin, the mouth, and body. By utilizing the "adult" characters, especially those exhibited by the oral and ventral suckers, the cercariæ may be placed in one or other of the four great groups into which the adult digenetic trematodes are subdivided, namely, Gasterostomidæ, Monostomidæ, Amphistomidæ and Distomidæ. (With the exception of a small group in which the body shows practically no internal differentiation and to which the special name "lophocerca" has been given.) For the purposes of differential diagnosis the cercariæ, being all at the same stage in development, may be regarded tentatively as a separate group of animals, and their differentiation based upon their most striking characters, whether they be "adult" or "larval." The classification of the cercariæ proposed by Lühe in 1909 resolves the distome cercariæ into easily recognizable subdivisions with a corresponding descriptive terminology derived partly from the generic nomenclature proposed by Diesing in 1858. These subdivisions are based upon the character of the tail.

LÜHE'S CLASSIFICATION.

A. GASTEROSTOME cercariæ.	Mouth opening in the middle of the ventral surface. Intestine simple sac-shaped. Two long projections from the end of the body.
B. MONOSTOME cercariæ.	Ventral sucker lacking.
C. AMPHISTOME cercariæ.	Ventral sucker at the posterior end of the body.
D. LOPHOCERCARIÆ.	Cercariæ with longitudinal cuticular projections along the sides of the body. Tail forked.
E. DISTOME cercariæ.	Ventral sucker towards middle of body.
(1) Cystocercous cercariæ.	Base of the tail forms a space into which the body can be drawn.
(2) Rhopalocercous cercariæ.	Tail having as great or greater width than the body.
(3) Leptocercous cercariæ.	Tail straight, slender, and narrower than the body.
(a) Gymnocephalous cercariæ.	Anterior end rounded, without stylet or boring spine.
(b) Echinostome cercariæ.	Anterior end with a collar and crown of thorns.
(c) Xiphidiocercariæ.	Anterior end with stylet.
(4) Trichocercous cercariæ.	Tail set with spines.
(5) Cercariæ.	Tail entirely undeveloped.
(6) Rattenkönigcercariæ.	Cercariæ with tails joined, forming a sort of colony.
(7) Microcercous cercariæ.	Tail stumpy.
(8) Furcocercous cercariæ.	Tail forked at its end.

DESCRIPTION OF BILHARZIA CERCARIÆ.

The various trematode larvæ found in each genus of fresh-water molluscs in Egypt are tabulated according to this classification and are described in a succeeding part. Their chief interest in relation to the present inquiry lies in their similarity to the *Bilharzia cercariæ*.



FIG. 45.

FIG. 46.

FIG. 47.

Various *Bilharzia cercariæ* found in molluscs around Cairo.

FIGS. 45, 46, in *Planorbis boissyi*. FIG. 47, in *Bullinus dybowski*.

When bilharzial cercariæ are seen floating in water the most noticeable character is the presence of a Y-shaped tail. This character is common to the group lophocerca and to the furcocercous division of the distomes. In the former group the ventral

sucker is absent, in the latter it is well developed. It is to this latter group that the *Bilharzia cercariæ* belong. The following furcocercous cercariæ were found: *C. vivax* in Cleopatra; *C. fissicauda* in *Bullinus*; a form very similar to *C. ocellata* in *Melania*, *Planorbis boissyi* and *P. mareoticus*, which we provisionally called "*C. bilharziella*"; and the cercariæ of bilharzia in *Bullinus* and in *P. boissyi*. *C. vivax* and *C. fissicauda* both possess a muscular pharynx behind the oral sucker, in the other forms this is absent. "*C. bilharzia*" and "*C. bilharziella*" are related and probably belong to closely allied genera in the family Bilharziidæ. "*C. bilharziella*" possesses a pair of pigment spots anterior to the ventral sucker and there is a cuticular keel along each side of the prongs of the tail. These are absent in the *Bilharzia cercariæ*.

The relation or identity of the *Bilharzia cercariæ* found in the molluscs *Bullinus* and *Planorbis* will be discussed in the articles dealing with the adult worms.

SKIN INFECTION.

Experimental evidence has already been given (p. 44) in favour of the direct penetration of the skin and of the mucous membrane of the mouth and gullet by the *Bilharzia cercaria*. Many writers appear to have the greatest reluctance in accepting the possibility of skin penetration. Some, like Allan, believe that infection is limited to the tender skin of the prepuce and advocate universal circumcision; Ruffer and others interpret infection during immersion in *Bilharzia*-infested countries as due to entrance of the cercaria through the anus.

In the *United States Naval Medical Bulletin* for October, 1915 (p. 648), Post writes that our experimental infection of rats by immersion "clearly shows, it seems to me, that the most usual port of entry must be the anus."

It may be pointed out, however, that: (a) Certain cercariæ are known to penetrate the tissues of the second intermediary host to encyst, and are provided with special glands and, in some cases, stylets to enable them to do this. (b) If a young rat or mouse be suspended in a large test-tube containing water full of *Bilharzia cercariæ*, these cercariæ can be seen to approach and fasten on to the limbs and body of the animal. When the animal is removed half an hour later, there remain in the fluid only a few cercariæ and a large number of *detached* tails. (c) A young mouse so immersed for half an hour was killed, and subsequently embedded whole in



FIG. 48.

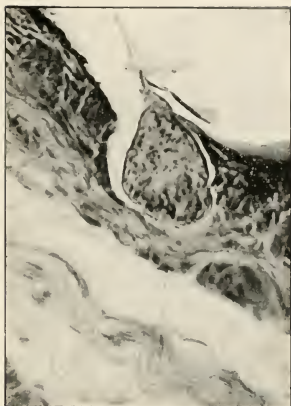


FIG. 49.

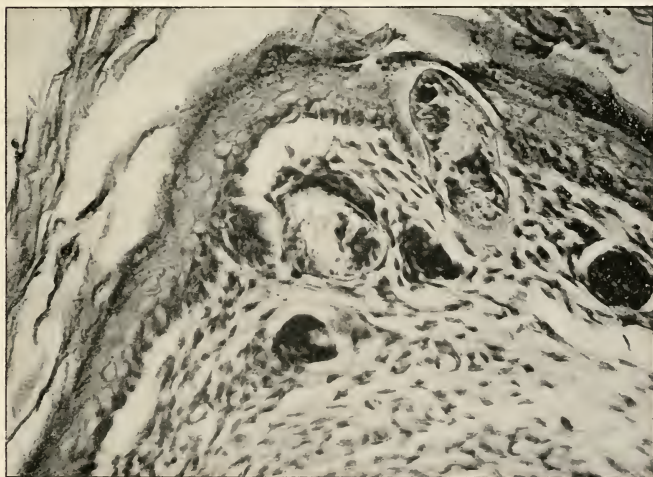


FIG. 50.

Figs. 48, 49, 50.—Micrograms of sections of skin of a newly born mouse which had been immersed for half an hour in water containing large numbers of *Bilharzia* cercariae.



FIG. 51

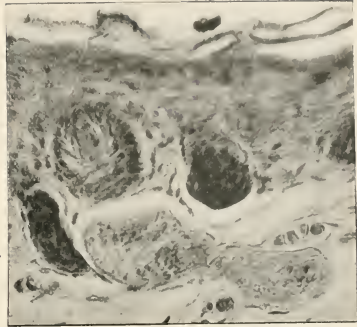


FIG. 52.

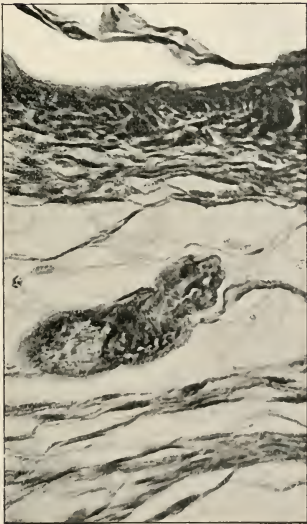


FIG. 53.



FIG. 54.

Figs. 51-54.—Sections of skin of a newly born mouse which had been immersed for half an hour in water containing large numbers of *Bilharzia* cercariae.

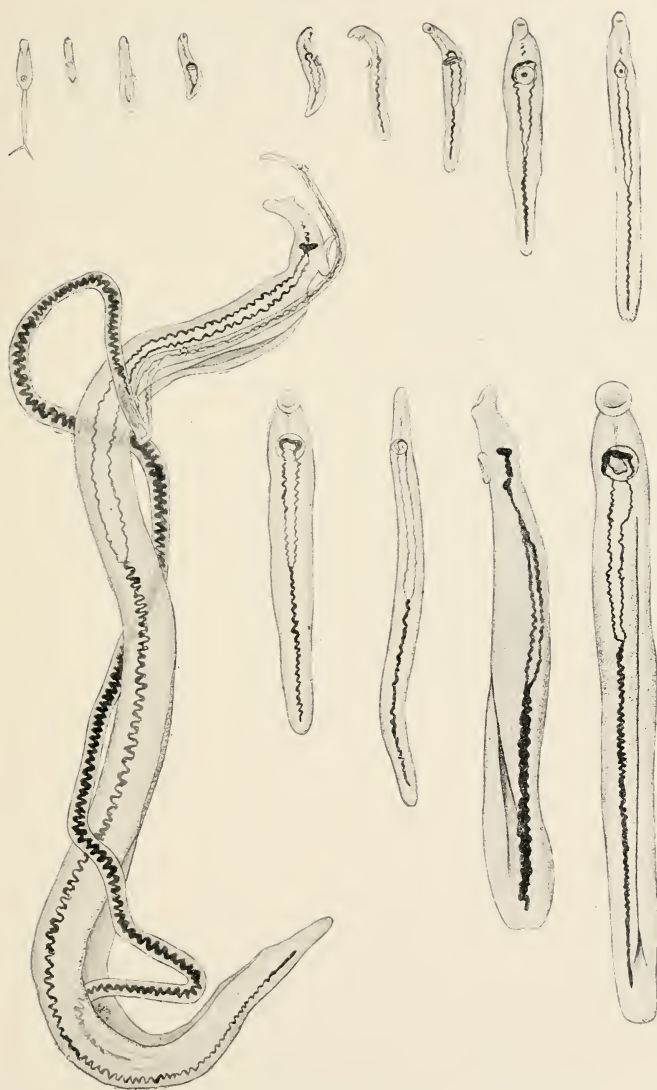


FIG. 55.—Bilharzia worms at various stages of development obtained from the liver of a rat and of a guinea-pig experimentally infected two months previously.

paraffin. Sections of the body and of the limbs showed the cercariæ at all stages of entry. They were found in the act of passing through the unbroken skin, and not through the pores or hair-follicles (*vide* figs 48 to 54).

The cercariæ seemed to be attracted by the warmth of the body, as similar evidence was rare in a recently dead mouse similarly immersed and the degree of penetration slight.

DEVELOPMENT IN THE DEFINITIVE HOST.

Once the cercaria has entered the definitive host it undergoes no further metamorphosis. There is gradual growth with differentiation of organs, and in *Bilharzia* with differentiation also of male and female individuals. The males are early recognizable from the females by their greater breadth and the stouter formation of the ventral sucker. In the accompanying plates is figured, under the same magnification, at the various stages, the gradual development of the adult body in all its phases from the cercaria before it enters to the paired egg-producing adults some months later. The route taken by the cercarial body in its transit from the skin to the portal system is still under investigation. It is noteworthy here, however, that the cercariæ do not all appear to arrive in the liver at the same time. Some of the smallest forms were obtained by teasing liver which contained also forms almost fully grown. This accords with Professor Looss's experience in ankylostome infection. A number of larvæ probably become "lost" in the tissues. It may be, however, that a certain number enter the bloodstream direct, while others pass first through the lymphatic system.

TABLE OF EGYPTIAN MOLLUSCS IN WHICH TREMATODE LARVÆ OCCUR.

Cercaria group	Host	PLANORBIS		Bulinus	Pygophysa	Physa	Limnea	Vivipara	Cleopatra	Lanistes	Bythinia	Melania
		Menetus	Gyraulus									
(A) GASTEROSTOME	..	..	..	..	..	..	..	..	..	..	..	..
(B) MONOSTOME ..	..	..	..	..	..	..	C. sp. ?	..	..	..	..	C. verrucosi
(C) AMPHISTOME ..	..	..	..	C. pigmentata	..	..	..	..	C. egyptiaca	..	..	..
(D) LOPHOCERCA	..	..	..	..	..	..	..	..	C. cristata	..	C. sp. ?	C. microcristata
(E) DISTOME—												
(1) Cystocercus ..	..	..	..	..	..	..	..	..	C. capsularia	..	..	..
(2) Rhopalocercus ..	..	..	..	..	..	..	..	..	..	..	..	..
(3) Leptocercus—												
(a) Gymnocephalous	..	..	..	C. sp. ?	..	C. sp. ?	C. obscura?	..	C. distomatosa	C. sp. ?	..	..
(b) Echinostome	C. sp. ?	..	..	C. agilis	..	..	..	..	C. exigua	..	C. sp. ?	C. cellulosa
(c) Xiphidocercaria	..	..	..	..	..	..	C. sp. ?	C. pusilla	..	..	..	C. microcotyla
(4) Trichoercus	..	..	..	..	..	..	..	..	C. microcotyla	..	..	..
(5) Cercariæ	..	..	..	..	..	..	..	..	..	..	..	..
(6) Rattenkönig-cercariæ	..	..	..	..	..	..	..	..	..	..	..	..
(7) Microercus	..	..	..	..	..	..	..	..	..	..	..	..
(8) Furcocercus	..	..	..	..	..	..	..	..	C. vivax	..	..	..
	C. bilharzia	..	..	C. fissicauda	..	..	..	..	..	..	..	..
	harzia	..	..	C. bilharzia	..	..	..	..	..	..	..	C. bilharziella
	mansonii	..	..	hematobium	..	..	..	..	..	..	..	..
	C. bilharziella	..	..	..	..	..	..	..	..	..	C. sp. ?	..

PART IV.
EGYPTIAN MOLLUSCA.

EGYPTIAN MOLLUSCA.

As a preliminary to the systematic dissection of molluscs for developmental stages of trematodes it was thought essential to form a typical set of the various species of Egyptian Mollusca for reference. Through the courtesy of Major Flower and Messrs. Nicoll and Bonhote, we were given full liberty to make an exhaustive examination of the various ponds in the Zoological Gardens, Giza. These waters proved particularly rich in molluscan fauna, and, as will be noticed from the localities given under each species, provided typical examples of the bulk of the recorded forms.

Molluscs are, generally speaking, essentially aquatic animals, but a certain number are adapted to terrestrial life. The latter are of interest in relation to these investigations only in so far as they may be found living on the weeds overhanging the canals or dead in the mud dredged for aquatic forms. A certain number which came under our purview in this way are put on record.

The larval metamorphosis of all digenetic trematodes occurs without known exception in the bodies of molluscs belonging to the classes Gastropoda and Lamellibranchia, which are comprised in the grade Prohipidoglossomorpha, and are alike distinguished by the possession of a visceral commissure, a foot wholly posterior to the head and a separation of direct communication between gonads and pericardium.

The large majority of trematode larvæ develop in the Gastropoda. The Gastropoda are specially characterized by a univalve shell, an asymmetrical organization and a well-developed head, while the Lamellibranchia have a bivalve shell, an internal and external symmetry and a rudimentary cephalic region.

The shells collected are described in accordance with the classification set out in the following table; in every case the diagnosis is provisional and is based upon a comparative study of the material with the figures and description given by Pallary in his "Catalogue de la Faune malacologique de l'Égypte," published in Cairo in 1909.

		CLASS GASTROPODA.			
EUTHYNEURA	Opisthobranchia	Tectibranchia	(marine forms)	Helicidae	{ HELIX.
		Nudibranchia		{ EREMINA.	
	Pulmonata	Stylommatophora		Pupidae	{ LEUCOCHILOIDES.
				Succineidae	{ CALAXIS.
		Basommatophora		Planorbidae	{ PLANORBIS.
					{ BULLINUS.
				Physidae	{ PYRGOPHYSA.
				Limnæidae	{ — PHYSA.
		Ancylidae	{ — LIMNÆA.		
					{ — ANCYLUS.
STREPTONEURA	Aspidobranchia	Docoglossa	— Neritidae	— Neritina.	
		Rhipidoglossa		{ VIVIPARA.	
	Pectiniobranchia	Tænioglossa—Platypoda—	Paludineidae	{ CLEOPATRA.	
			Ampullariidae	{ AMPULLARIA.	
		Valvatidae	— Lanistes.		
			Hydrobiidae	{ BYTHINIA.	
		Stenoglossa	— Valvata.		
			{ Toxiglossa	{ HYDROBIA.	
		{ Rhachiglossa	{ — MELANIA.		
		CLASS LAMELLIBRANCHIA.			
Eulamellibranchia—Submytilacea—		Cyrenidae	— CORBICULA.		
		Cycladidae	{ CYCLAS (SPHÆRIUM).		
			{ PISIDIUM.		
		Unionidae	{ EUPERA.		
			{ NODULARIA.		
		Mutelidae	{ LAMELLIDENS.		
			{ MUTEA.		
			{ SPATHA.		

GASTROPODA.

HELICIDÆ.

Helix (Hygromanes) obstructa, Ferussac, 1821.

Common among the overhanging grass along the edges of the ponds in the Zoological Gardens at Giza.

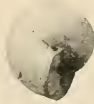


FIG. 56.—*Hygromanes obstructa*. (× 2.)

Stated by Pallary to be common throughout the Delta, but not found by us elsewhere than above.

Helix (Cochlicella) barbara, Linnæus, 1758.

Common in the Zoological Gardens, Giza, associated with *Hygromanes obstructa*.



FIG. 57.—*Helix barbara*. (× 2.)

Recorded by Pallary as not uncommon around Alexandria.

Eremina desertorum, Forskal, 1775.

Common on the Mokattam Hills east of Cairo. Is said to occur over the whole Desert of North Africa from South Tunis to the Red Sea. This species has a remarkable capacity of withstanding adverse conditions. A specimen stuck down on a tablet in the British Museum, 1846, was found to be alive four years later, and survived two more years. The Rev. A. H. Cooke kept ten examples alive in a tin box without food for eight years.



FIG. 58.—*Eremina desertorum*. (× 1.)

An additional point of interest attaches to this species from the fact that in all probability it was the one upon which the survivors of H.M.S. "Tara" are reported to have fed during their captivity with the Senussi near Sollum prior to their rescue by the Duke of Westminster's armoured car detachment in the spring of 1916.

PUPIDÆ.

Leucochiloides sennaaricus, Pfeiffer, 1855.



FIG. 59.—*Leucochiloides sennaaricus*. (× 3.)

Shells only, recovered from the fine mud dredged from the artificial ponds in the Zoological Gardens at Giza. Not frequent.

Teilhard has found it in abundance at Matarieh and occasionally in the Wadi Hoff near Helwan.

Calaxis unidentata, Jickeli, 1874.

Collected with *L. sennaaricus* from mud dredged in the ponds at the Giza Zoological Gardens.



FIG. 60.—*Calaxis unidentata*. ($\times 3$.)

Reported as common at Matarieh and around Alexandria.

SUCCINEIDÆ.

Succinea cleopatra, Pallary, 1909.

(? *Succinea ægyptiaca*, Ehrenberg, 1830.)

Several specimens collected from reeds in marshy land on the desert side of the Ismailia Canal south of Bilbeis. A single



FIG. 61.—*Succinea cleopatra*. ($\times 1\frac{1}{2}$.)

example taken on the Sweet Water Canal near its connection with Lake Timsah.

Reported from the Mahmoud Canal and Lake Hadra near Alexandria, and from Nefisha near Ismailia.

PLANORBIDÆ.

Planorbis boissyi, Potiez and Michaud, 1838.

Next to *Bullinus dybowski* this is the commonest mollusc in the small canals and ditches round Marg. We found it plentiful also on the road to Bilbeis from the south in a small canal running parallel to the Ismailia Canal. In the marshes to the south-west of the town of Ismailia it was also abundant. In other localities where we collected around Cairo and in the ponds of the Zoological Gardens it appeared to be entirely absent.

Pallary records specimens from the canals at Alexandria, at Samanoud and Cairo—"in a word, throughout Lower Egypt." From our experience, however, it certainly appears to have a very limited distribution as compared with *Bullinus* and other common forms in the Delta.



FIG. 62.—*Planorbis boissyi*. ($\times 1$.)

In the Sudan, where intestinal schistosomiasis is fairly common, this species has a wide distribution. Mrs. Longstaff has recorded finds at the following places on the course of the White Nile: north and south of Lake No; at Abba Island, Hillet Abbás, Gebel Ên, Bahr-el-Zarâfa, and Hillet-al-Nûwêr. The Swedish Expedition collected numerous young examples at Gebel Ahmad Aga. These places are shown on the accompanying map.

Planorbis laurenti, Bourguignat, reported from Lake Timsah and from marshes near Ismailia, appears to be the same as *P. boissyi*.

P. boissyi is the intermediate host of *Bilharzia mansoni* in man in Egypt. The *Cercaria* of *Bilharzia mansoni* is shown in fig. 45. It harbours also the developmental stages of a second species of bilharzid worm believed to attain maturity in an aquatic bird.

Planorbis (segmentina) angusta, Jickeli, 1874.

A single shell of this species was given to us by Dr. Innes, from



FIG. 63.—*Planorbis (segmentina) angusta*. ($\times 3$.)

his collection made on the White Nile. We have found dead specimens in our field work. It is recorded from the shore of Lake Mariout, near Mex, Alexandria.

Planorbis mareoticus, Innes, 1884.

This small *Planorbis* is very common in the ponds at the Zoological Gardens and elsewhere in Giza. Specimens were frequently found at Marg.



FIG. 64.—*Planorbis mareoticus*. ($\times 1\frac{1}{2}$.)

Pallary says that it is found at Damanhour, Nefische, near Ismailia, and is very common around Alexandria.

Ancey is of opinion that this form is the same as *P. ehrenbergi*.

P. mareoticus is the intermediate host of a cercaria believed to be the infective stage of a species of bilharzid worm occurring in aquatic birds.

EGG DEPOSITION IN PLANORBIDÆ.

Among the fresh-water molluscs at Marg we noticed two types of reproduction. There were certain forms like *Vivipara* and *Melania* in which the eggs were retained until development had taken place to such a degree that the progeny were provided with a shell showing already characters of the adult.



FIG. 65.—An egg-mass of *Bullinus* sp. deposited on weed.

In other forms, such as *Bullinus* and *Planorbis*, the eggs were found deposited in flat jelly-like masses on weed from the bottom and sides of the stream. Not infrequently similar gelatinous masses were found on the shells of *Planorbis* and *Bullinus*. That these were deposited by the individual actually inhabiting the shell seemed little probable.

Bullinus contortus, Michaud, 1829.

Common in the ponds of the Zoological Gardens, Giza, at Marg, and on the Sweet Water Canal, usually associated with *B. dybowski*.



FIG. 66.—*Bullinus contortus*. ($\times 2$)

Mrs. Longstaff has found it at Lake Shambe and at Masran Island on the White Nile. It has a very wide range, being reported from North, West and South Africa, Abyssinia, the Euphrates, and South Europe.

B. contortus is one of the intermediate hosts of *Bilharzia hamatobium* (*sens. strictu*) in man in Egypt.

Bullinus dybowski, Fischer, 1891.

Very common in the ponds at the Zoological Gardens, at Marg, on the Sweet-water Canal and generally in the canals and birkets.



FIG. 67.—*Bullinus dybowski*. ($\times 2$)

Teilhard records it from Matarieh, and Pallary notes its occurrence in the collections of Lhotellerie from around Alexandria. This form is said by Pallary to be that provisionally named by Dr. Innes *Physa alexandrina* and appears in the lists of Sonsino and Looss under this synonym.

B. dybowski and *B. alexandrina* are intermediate hosts of *Bilharzia hamatobium* (*sens. strictu*) in man in Egypt. The cercaria is shown in fig. 47.

Bullinus innesi, Bourguignat.

A number of specimens found associated with the two pre-

ceding forms at Marg. Teilhard obtained specimens at Matarieh and Lhotellerie from the Mahmoud Canal near Alexandria.

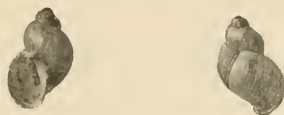


FIG. 68.—*Bullinus innesi*. ($\times 2$.)

Bullinus innesi on some occasions was found infected with cercariae of *Bilharzia hæmatobium* (*sens. strictu*).

Bullinus (*Pyrgophysa*) *forskali*, Ehrenberg, 1831.

Fairly common in the canal in the village at Marg and in the small subsidiaries. It was apparently absent from the Zoological Gardens. It is stated by Pallary to occur throughout the course of the Nile. In the Sudan Mrs. Longstaff found a specimen alive in



FIG. 69.—*Bullinus* (*Pyrgophysa*) *forskali*. ($\times 2$.)

Lake Shambe, and Dr. Innes describes material from a marsh near the Blue Nile.

Bullinus (*Physopsis*) spp.

Pallary considers the records of the occurrence in Egypt (Damanhour) of this sub-section of the genus *Bullinus* as referable to young specimens of *Physa acuta* and *P. subopaca*.

(?) *Physa acuta*, Draparnaud, 1805.

Some specimens collected from a pond north of Suez and submitted for diagnosis by Lieutenant-Colonel A. Balfour, C.M.G., appear to belong to this species. They closely resembled the species illustrated in fig. 70, but were twice the size.

Physa subopaca, Lamarck, 1841.

Fairly common in a small irrigation canal in the public gardens south of the outflow branch of the Sweet Water Canal passing

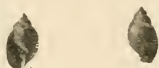


FIG. 70.—*Physa subopaca*.

through the town of Ismailia. A few examples got in Giza Canal. Found at Ismailia also by Letourneux, at Matarieh by Teilhard, and around Alexandria by Lhotellerie.

LIMNAEIDÆ.

Limnæa cailliaudi, Bourguignat, 1883.

At Marg, but not in very large numbers.



FIG. 71.—*Limnæa cailliaudi*. ($\times 1\frac{1}{2}$.)

Letourneux obtained this species on the shores of Choubrah Island, a few miles to the north of Cairo. A small variety has been found at Alexandria and Ismailia.

Limnæa alexandrina, Bourguignat, 1883.

Common in the Zoological Gardens, in the fountain of Shepheard's Hotel garden, and in the ponds in Esbekieh Gardens,



FIG. 72.—*Limnæa*, sp. inq. ($\times 1\frac{1}{2}$.)

Cairo; and in collections of water generally where there is considerable weed.

In marshy pools on the desert side of the Ismailia Canal near Bilbeis a peculiar variety [Fig. 72] of *Limnæa*, differing apparently from those recorded for Egypt, was found in numbers.

(?) *Limnæa truncatula*, Müller.

Found in large numbers in small irrigation channels on the Island of Gezireh, in the ponds in the Zoological Gardens, Giza, and in irrigation channels in agricultural land south of Bilbeis. This form, curiously enough, is entirely absent from Marg.

The specimens differ slightly, but apparently constantly, from typical examples of this species received from England, and there is some probability that the Egyptian material should be placed



FIG. 73.—*Limnæa truncatula*, inq. ($\times 1\frac{1}{2}$.)

under a separate category. Pallary states, however, that *L. truncatula* and a variety *minuta* is found throughout the course of the Nile.

The occurrence of this form in large numbers in Egypt is apparently overlooked by Looss in his discussion on the carrier of the liver-fluke of sheep and cattle in Egypt.

ANCYLIDÆ.

Ancylus clessini, Jickeli, 1882.

A few specimens of this small limpet were occasionally found on dead leaves dredged from the bottom of the ponds in the Zoological Gardens, Giza. The species has been recorded once previously, and was collected by Lhotellerie at Alexandria.

PALUDINIDÆ.

Vivipara unicolor, Olivier, 1801.

Of constant occurrence in all our collections. Very common in the ponds at the Zoological Gardens and at Marg.

Stated by Pallary to occur throughout the course of the Nile and its tributaries.

Like other operculated forms it can survive for a considerable period without water.



FIG. 74.—*Vivipara unicolor*. ($\times 1\frac{1}{2}$.)

There are a number of varieties, based upon colour and ridges on the shell.

Cleopatra bulimoides, Olivier, 1804.

Widespread in distribution and of common occurrence. Found in numbers in mud from canals, at the Zoological Gardens, at Marg, and elsewhere.



FIG. 75.—*Cleopatra bulimoides*. ($\times 1\frac{1}{2}$.)

Stated by Pallary to occur throughout the course of the Nile.

We distinguished specimens of this species provisionally from the succeeding form by the brown spiral marking of the shell.

Cleopatra cyclostomoides, Küster, 1852.

Common and found in association with the preceding form, from which we distinguish it empirically by its greenish uniform coloration.

There appears to be a number of varieties of shell types in *Cleopatra bulimoides*.

AMPULLARIDÆ.

Ampullaria ovata, Olivier, 1804.

Found only, but in considerable numbers, in the Bahr Yusef in

the Fayum. There are records of its occurrence in Lake Mariut and in the Mahmoudieh Canal near Alexandria.



FIG. 76.—*Ampullaria ovata*. ($\times 1$.)

Lanistes boltzeni, Chemnitz, 1786.

Fairly frequent in the Marg Canal in and beyond the village. Some examples dredged from the ferry across the Sweet Water Canal in the town of Ismailia.



FIG. 77.—*Lanistes boltzeni*. ($\times 1$.)

It is said by Pallary to occur along the whole course of the Nile.

VALVATIDÆ.

Valvata nilotica, Jickeli, 1874.

This minute form occurs in numbers on dead leaves in the ponds in the Zoological Gardens, Giza. Examples were also collected from the large Giza Canal. It occurred only very occasionally at Marg.

Pallary has specimens from Alexandria, Cairo, and Suez. He states that it is distributed along the Nile and its tributaries.



FIG. 78.—*Valvata nilotica*. (× 2.)

HYDROBIIDÆ.

Bythinia (Gabbia) senaarica, Parreys, 1853.

About eighteen specimens in all occurred amongst the material collected from Marg. A few examples were found in the ponds of



FIG. 79.—*Bythinia (Gabbia) senaarica*. (× 2.)

the Zoological Gardens, Giza, and a couple were dredged from the ferry over the Sweet Water Canal at Ismailia.

Pallary does not give specific localities, but says that it is distributed along the whole Nile. Mrs. Longstaff collected specimens from "ponds near the Pyramids of Gizeh" and at several places on the White Nile.

Hydrobia stagnalis, Linnæus.

We failed to find this form. It is reported by Pallary to occur in Lake Mariout, Alexandria, and at Rosetta. Smith mentions its

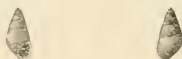


FIG. 80.—*Hydrobia stagnalis*, Bgt. (× 2.)

presence in Lake Qurun, Fayum and Jickeli lists it for North-East Africa.

MELANIIDÆ.

Melania tuberculata, Müller, 1774.

This is a very common form lying usually on the surface of the mud at the bottom of canals, ponds and birkets. It varies greatly in size. The largest forms collected were those obtained from the ponds in the Zoological Gardens,

Specimens were less frequent at Marg than *Vivipara* or *Cleopatra*. Pallary's records are from the neighbourhood of Alexandria, from Asswan and from Suez.



FIG. 81.—*Melania tuberculata*. ($\times 1\frac{1}{2}$.)

In the bed of a small channel running from a spring into Lake Timsah between Ismailia and Ferry Post very large numbers of a small black variety were readily discernible on the sandy bottom.

Melania tuberculata harbours the developmental stages of a bilharzid worm believed to attain maturity in some aquatic bird.

LAMELLIBRANCHIA.

CYRENIDÆ.

Corbicula consobrina, Cailiaud, 1828.

In the mud of all the ponds and canals examined this bivalve

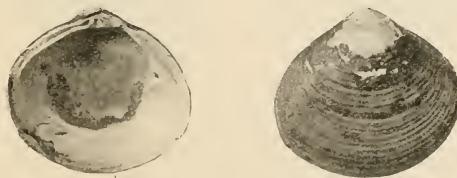


FIG. 82.—*Corbicula consobrina*. ($\times 1$.)

occurred in large numbers. On the newly made banks of the tertiary canals, resulting from the annual removal of the mud from

the bed of the canal, enormous numbers of dead and disintegrating shells can always be seen.

Pallary gives no locality but says that this species is very common in all the waters of Egypt.

CYCLADIDÆ.

Cyclas (Sphærium) teilhardi, Pallary, 1909.

A few examples were collected from the ponds in the Zoological Gardens at Giza.



FIG. 83.—*Cyclas (Sphærium) teilhardi*. ($\times 1\frac{1}{2}$.)

Pallary bases the species on material collected at Gabbari near Alexandria.

MUTELIDÆ.

Spatha rubens, Lamarck, 1819.

A few examples of this enormous bivalve were dredged in the Zoological Gardens.

It is stated by Pallary to occur in the waters of the Nile and in the canals of the Delta.

UNIONIDÆ.

Nodularia nilotica, Cailliaud, 1823.

Frequent in mud from ponds in the Zoological Gardens and from the Ismailia Canal.



FIG. 84.—*Nodularia nilotica*. ($\times 1$.)

Pallary states that this species is rarely found in typical form, but it occurs throughout the course of the Nile.

ACKNOWLEDGMENTS.

The present section completes the account of the investigations in the field. These extended from February until July of 1915, and were continued, under the auspices of the Wandsworth Trust, from November until February of the present year. Throughout the whole period of my mission I enjoyed the full use of the laboratories of the Department of Biology and Parasitology in the Government School of Medicine, Cairo. I now desire to put on record my deep sense of gratitude to the school authorities, and particularly to the director, Dr. H. P. Keatinge, who took a keen personal interest in the progress of the inquiry. I was also indebted in the earlier stages to Dr. A. R. Ferguson, Professor of Pathology, and later to Dr. W. H. Wilson, Professor of Physiology, for their kind and helpful advice.

At various times I had to seek official information and expert opinion, which was always most cordially given, from a number of other Government departments in Egypt. Dr. Charles Todd, chief of the Bacteriological Institute; Mr. E. Hurst, of the Physical Science Department; Messrs. Lucas and Pollard, of the Chemical Laboratory; Mr. J. I. Craig, of the Statistical Department; Major Flower and Messrs. Nicoll and Bonhote, of the Zoological Service; Mr. Branch, Secretary of the Sultanieh Society of Agriculture; Mr. Adamson, chief of the First Irrigation Circle; and Mr. W. A. Maule, of the Egyptian Government Survey, are amongst those to whom I am especially indebted for help on particular aspects of the Bilharzia problem, as it presented itself in Egypt.

I take also the opportunity which presents itself here to acknowledge my obligations for the valuable help received from Drs. Cockin and Thomson. Dr. Cockin unfortunately met with an accident early in March, and was invalided home. Dr. J. Gordon Thomson devoted himself with single-minded energy to the laborious work of collecting and prosecuting, and although he personally wished to join for general service in the Royal Army Medical Corps in May, he was good enough to remain with me until the beginning of July. A considerable number of the molluscs, figured in the present section, and of the cercariæ listed, were accumulated through his labours. It was in one of his dissections that the cercaria of the *Bilharzia mansoni* was first recognized.

I have pleasure, too, in bringing under notice the valuable services given by W. McDonald throughout the whole year's work both in the field and in the laboratory. I have no hesitation in saying that it was mainly due to his sustained application and persistent loyalty in following out my instructions that the cercaria of *Bilharzia hamatobium* was discovered. The sections showing the cercariæ entering the skin and some of the illustrations in this report testify to his technical skill.

PART V.
ADULTS AND OVA.

ADULTS AND OVA.

THE morphology of the adult worms, and of the eggs recovered from cases of bilharziosis in Egypt, has been dealt with exhaustively by several previous writers, notably by Bilharz, Leuckart, Fritsch, Lortet and Vailleton, and particularly by Looss.

In parasites generally there are certain small variations within the limits of a species both in size, shape, etc., of adults and of eggs. In *Bilharzia haematobia* unusually striking and constantly recurring departures from the normal have been described. In Looss' monograph on the adult anatomy it is recognized that a number of these do actually occur, but others are, in his opinion, due to errors in interpretation by previous workers. These abnormalities, rather than the normal anatomy, are our more immediate concern. The differences that have been recorded in the shape of the eggs are of special interest. As early as 1851 Bilharz had noticed that certain of these, passed in the faeces, were distorted, the small terminal spine of the typical egg being apparently displaced laterally. These lateral-spined eggs he regarded as abnormalities.

DUALITY THEORY.

In 1864 Harley [214] was so struck by the absence of these atypical forms in cases of bilharziosis seen in South Africa, that he named the South African parasite *Distoma*

capense, to distinguish it from the Egyptian parasite which gave rise to both types of eggs. The subject remained one of merely academic interest until 1902, when Sir Patrick Manson saw in London a case of intestinal bilharziosis, contracted in the West Indies, in which lateral-spined eggs only were present. In the following year he put forward the suggestion that: "Possibly there are two species of Bilharzia, one with lateral-spined ova, depositing its eggs in the rectum only, the other haunting bladder or rectum indifferently" [328]. This view was revitalized by Sambon in a series of papers, commencing with one in 1907, in which he formally named the new species after Sir Patrick Manson, "in appreciation of this, one of his many genial intuitions" [425, 426, 427, 428]. Sambon's new species met with an unsympathetic reception, more especially from Looss, who held, with many elaborate arguments, and with some apparent success, that vesical and intestinal lesions in bilharzial infections in Egypt were caused solely by the one species, *B. hæmatobia*. The whole controversy cannot be reviewed here, but the curious reader will find in the prolonged debate "a stimulating vituperativeness" which makes it highly entertaining, if somewhat cruel reading.

In his "Remarks on *Schistosomum mansoni*," Sambon [425] explained that his "determination is based principally on the characters of the eggs," but that, in addition, he had "taken into consideration their different geographical distribution, the different anatomical habitat, and the different pathogeny of the two species." He maintained that "the lateral-spined ova are not found occasionally only, within the distributional areas of *S. hæmatobium*, as would necessarily be the case if they were the product of this species, but have a peculiar and wide geographical distribution of their own, being absent in many places where endemic hæmaturia and its causative agent are prevalent (Cyprus, South Africa)."

The opposing theory put forward by Looss was, briefly, that "unfertilized females are not capable of producing other than abnormal eggs." These abnormal eggs were for the most part the lateral-spined variety, and where they contained a miracidium this was attributed to parthenogenesis. Looss' position, which met with clever criticism from Sambon, became somewhat changed later in the light of his own further observations, but his main tenets remained, and his final ground became, theoretically, unassailable without the aid of experimental evidence.

In Looss' opinion "the strange and striking differences presented by the clinical and pathological pictures of bilharziosis as seen in various places" could be explained "on the presumptive life history of the parasite, in connexion with the habits of the host and the conditions of the country" [295].

Commencing with his postulate that infection is direct and takes place at all times through the skin, he maintained that the miracidia proceed to the

liver, where they develop into sporocysts, from which worms escape later into the portal veins. As at post-mortems it is not uncommon to find males, obviously of the same size and age, alone in the portal vein, he assumed that "they must have been generated at about the same time; this would become comprehensible on the assumption that they were generated in one sporocyst." The female worms which are less common likewise would originate from a sporocyst. Applying these postulates to the ordinary conditions found in the Delta, it appeared to Looss that "several miracidia penetrate the body at short intervals and thus males and females will be present." "In this case the females will not have long to wait for fertilization." While waiting they will have produced a few abnormal eggs but being almost immediately captured by the males are carried off to the pelvic organs, with the result that "there is urinary bilharziosis characterized by the apparition of terminal-spined eggs in the urine; the same eggs may appear in the fæces, but the lateral-spined ones will be so scarce that they seem to be altogether absent" [295].

In countries where conditions are unfavourable for infection, i.e., where the population is scattered and the people do not bathe in crowds, or where water is scanty or swiftly running, and the chances of miracidia entering the skin are small, then the following train of events may be presumed: "On a single occasion a few miracidia manage to enter the skin and one gets safely to the liver. It produces males. The worms grow to sexual maturity, but finding no females they wait for a certain time and then undertake the journey to the pelvic organs alone. The liver is again free from worms: the infection remains without consequences." This may recur as male producing miracidia are so common. Eventually a miracidium enters alone which gives rise to female worms. In due time these "begin to lay lateral-spined eggs. The oviposition goes on, perhaps, for a long time. The number of lateral-spined eggs increases steadily; all are carried to the liver." Some of these worms may migrate successfully as far as the large bowel.

Eventually there will be a "strong infection of the liver and some isolated patches in the wall of the intestine, but no terminal-spined ova will ever appear, nor will there be a regular infection of the bladder. After some time, the lateral-spined eggs of the liver begin to appear in the fæces, and they continue being voided in this way for several years."

Looss details other circumstances under which a secondary infection with terminal-spined eggs may be contracted by a case showing originally Manson's intestinal bilharziosis if a sufficient interval has lapsed between the entry of the two miracidia. Lastly, infection by a large number of miracidia at a single exposure would result in a pure case of "urinary bilharziosis" [295].

Looss concludes that, from his point of view, "no sharp line of demarcation between the two types" exists. "They are simply the opposite ends of a continuous series of intermediary stages" [295].

LOOSS'
CRITICISM OF
SAMBON'S
SPECIES.

After detailed criticism of Sambon's arguments, Looss dismisses them with the conclusion that "in all the evidence there is not the slightest detail which would really point to the existence of a distinct species in the West Indies and certain parts of Africa." He adds that one of the fundamental facts on which his views rest is that in 1852 Bilharz actually found in Egypt that "the eggs of *S. hæmatobium* and *S. mansoni* may occur in one and the same individual."

SAMBON'S
REPLY.

Replying in 1909, Sambon [428] pertinently points out that Bilharz's alleged observation has never been confirmed and that the interpretation that both lateral-spined and terminal-spined eggs were actually seen in the same individual worm does not necessarily follow from Bilharz's statement. In turn he attacks Looss' hypothesis, especially his assumption of the occurrence of parthenogenesis in the adults.

LOOSS'
READJUSTMENT.

The effectiveness of this criticism is revealed by the readjustment of his position by Looss in 1911 [298]. He now recognized that "the question of the formation of these eggs and the question of their fertilization are in reality independent." He is still of opinion that the uncopulated females are incapable of giving their eggs the normal shape. After fertilization the change to normal shape will not take place immediately; there will always be a transition period. There is thus no longer any necessity of admitting on the part of the egg cell a capability of developing by parthenogenesis." "I have received the impression that when once the production of normal eggs begins, the others are, as a rule, quickly evacuated." "That the females of *S. hæmatobium* can, and do, produce the two forms of eggs is beyond question even now."

VIA MEDIA. American parasitologists attempted to settle the controversy by suggesting that possibly the eggs of *S. mansoni* were normal eggs similar to the abnormal forms, with distorted spine, produced by *S. hæmatobium* [271].

BEARINGS
ON PRESENT
INQUIRY.

Obviously the possibility that, in Egypt, man harboured two distinct species of bilharzia worm complicated the transmission problem, already rendered intricate by the presence there of bovine and avian infections.

It was realized, however, that the full solution was not an essential preliminary to the conduct of experiments which were more urgently needed to provide the necessary data on which to base prophylactic measures for the protection of the troops. The *Bilharzia cercariæ* found in *Bullinus* and in *Planorbis*, as well as other cercariæ, were found to react in a practically identical manner to changes in their environment; whether these were physical, such as exposure to heat, drying, etc., or chemical, such as exposure to dilute amounts of sodium bisulphate, etc. The *B. cercariæ* showed the same limited capacity to survive in water and

caused local irritation due to penetration of the skin in animals exposed to infection by immersion. Thus the earlier parts of this report were written with reference to "bilharzia," without touching (save inadvertently by the use of "*B. hamatobia*" in the old inclusive sense) on the problem of the unity or duality of the parasite concerned in the causation of bilharziosis. Indeed, the success of these experiments led to a further delay. The lethal effect of very dilute solutions of coal tar derivatives on the cercariæ raised the hope that if minute quantities of these substances could be got into the portal system unchanged, they might be found to destroy the bilharzia worms there. Thus, by cutting short the egg-laying period, the subsequent severity and duration of an infection might be considerably diminished.

Surgeon-General Ford was of opinion that a satisfactory method of treatment might prove of considerable service. Expert co-operation in the pharmacological aspects of the problem was obviously desirable. As soon, therefore, as it was evident that animals were being infected successfully, I decided to infect as many animals as were then available and to return to England to carry on further work on these lines. Infections were accordingly made from *P. boissyi* and from *Bullinus*. It was hoped that these would provide material still needed for the zoological inquiries not yet completed. A return in the autumn was foreshadowed, if facilities were obtainable, in the event of the need arising for further investigations through failure of the material or the upcrop of new problems.

EXPERIMENTAL
TREATMENT
NEGATIVE.

Most of the infected animals survived the homeward journey. Dr. H. H. Dale, F.R.S., kindly carried out a series of tests and the animals were afterwards dissected. It was agreed that none of the substances of known anthelmintic or cercariacidal value could be introduced into the portal system in doses lethal to adult parasites. This cleared the ground for a continuation of study of the specific nature of the cercariæ found respectively in *Bullinus* and *Planorbis*.

THE CERCARIÆ
IN *Planorbis*
AND *Bullinus*.

In addition to the cercaria provisionally identified as that of an avian bilharzia worm, three bilharzia cercariæ were provisionally differentiated from material collected at El Marg (figs. 45, 46, 47, Part III). Of these, one (fig. 45) infested *P. boissyi*; with it, later, but seen much less frequently, was a large form (fig. 46). This mollusc was not found in some other villages where bilharziosis was also prevalent. It was, therefore, apparent that even if eventually it was proved to be a carrier of infection to man, other species of mollusca must also be concerned. The search was therefore continued, and several weeks later, at the commencement of June, examples of the genus *Bullinus* were found to be likewise infested with *Bilharzia cercariæ* of slightly different appearance (fig. 47). As cercariæ, naturally discharged, became available from each source, animals were submitted to infection by immersion, and later by the mouth,

The animals first submitted to infection died from blockage of vessels by the growing worms before these had attained their full size. Such hyperinfection was at first courted to establish the fact that the animals in experimental use were actually susceptible. Later this had to be avoided to ensure that the infected animals would survive sufficiently long to show the effect of drug treatment on the worms in the portal system, and to give the growing worms sufficient time to attain sexual maturity and produce eggs whereby the specific character of the infection could be finally identified. This proved a much more difficult task. Too slight an immersion might result in a failure to infect or a failure to infect with enough to ensure the presence of females as well as males. Mishaps from all these causes befell in the animals taken to England, and as will be seen, necessitated a return to Egypt for further material.

EARLY APPEARANCE OF LATERAL-SPINED EGGS. Before leaving for London, two or three eggs only were seen. The first occurred in a female taken from the mesentery of a mouse that had survived until June 24. The others were seen a few days prior to sailing. These eggs were lateral-spined and were the result of infection with cercariæ from *P. boissyi*. According to Looss' theory these were the early abnormal products of young sexually mature females of *B. hæmatobia*; according to Sambon they should be regarded as characteristic ova of *B. mansoni*, the cause of intestinal bilharziosis; according to American parasitologists, they were merely early abnormal products of *B. hæmatobia*, simulating the true lateral-spined egg of *B. mansoni*, the cause of bilharziosis in the New World. Males were present as well as females, but this fact had now no significance, since Looss had himself abandoned the view that the females produced eggs parthenogenetically. The females found had only reached the egg-laying state. It was possible that they were just entering Looss' "transition period."

Sufficient time had not elapsed since the submission of animals to infection from *Bullinus* to warrant an examination of these prior to sailing.

After reaching London, in July, animals continued, as before, to die from hyperinfection with young adults. At the beginning of August, four monkeys which it had been hoped would survive several months, began to pass eggs and died within a fortnight of intense infection. These eggs were lateral-spined. The cercariæ used had been obtained from *P. boissyi*. No other type of egg was found. It could not be said, however, that the worms had become mature sufficiently long to have passed through Looss' "transition period."

LATER RESULTS. Certain of the rats which had survived until September showed at post-mortem an extraordinary condition of the liver. This was enlarged and deeply pigmented with black amorphous granules. The surface was speckled with minute white spots. These were found to contain accumulations of lateral-spined eggs. The final peripheral veins were frequented by paired adult worms. The liver

from these cases was macerated and the eggs released in enormous numbers. Every described variation in size and shape of lateral-spined egg was then found, but no terminal-spined eggs were seen. These animals had been infected from *P. boissyi*.

It had proved impossible to obtain material of the occasional large cercaria in *P. boissyi* for experimental purposes, but it was anticipated that in the very large series of infections made with cercariæ from *P. boissyi* for the experiments with drugs this cercaria would give evidence of its presence. Neither in the eggs nor adults resulting, however, was any indication seen of another species. The nature of this large cercaria remained, therefore, a perplexing mystery.

During September the animals submitted to very slight infection were still alive and were anxiously watched for evidence of successful infection. No eggs were passed, and as the length of time that had now elapsed since immersion was considered sufficient to allow of the worms attaining sexual maturity, those treated with cercariæ from *Bullinus* were killed and examined. The results were disappointing. It was evident that in the attempt to infect so slightly as to ensure the survival of the animals for some months the number of cercariæ that had actually entered had not been sufficient to ensure successful infection with paired adults. This experiment was repeated with certain of the animals slightly infected with cercariæ from *P. boissyi*. No adult worms were found.

Reviewing the position early in October, I realized that the materials now available were insufficient to enable me to deal effectively with the question of the zoological relationship of the bilharzia worms that caused the symptoms of vesical and intestinal bilharziosis. Certain facts might justify a reopening of the Sambon-Looss controversy, which had reached a position of stalemate, but they would not render the final position taken by Looss untenable. With the *B. cercariæ* available, it was clear that a complete solution was possible. The completion of this report was, therefore, postponed. I was granted permission to return to Egypt, and was enabled to do so by the Committee of the London School of Tropical Medicine, which allowed me to resume an unexpired portion of the Wandsworth Research Scholarship, which I had previously held.

Two series of experiments were seen to be required and were instigated immediately after I reached Egypt in November:—

(1) To lightly infect animals with *P. boissyi* cercariæ so that they would survive several months and thus enable the female bilharzia worms to pass the "transition period."

(2) To heavily infect animals with *Bullinus* cercariæ to ensure a successful diagnosis of the specific nature of this form. In view of the successful and heavy infections that had followed the administration of *P. boissyi* cercariæ by the mouth, it was decided to make the crucial experi-

ments by this method, which appeared to afford a more accurate means of control in the dosage. To ensure longevity monkeys were used. Additional experiments were made by immersing rats and mice in infective fluid, and other monkeys were subjected to skin infection.

These new experiments proved, after the necessary lapse of time, completely successful.

The smaller animals were killed week by week to watch the progress of the development. Worms were first recovered from a mouse, infected by immersion, on the seventeenth day. These were of course, very immature, but they showed differences in the development of the gut from those previously reared from *P. boissyi*. This difference persisted during the growth of the worms, as seen from later dissections, until the adult size was almost reached. The two lateral branches of the gut failed to unite early. In several of the experiments, males only were found. After five weeks, males and immature females were recovered from the mesenteric vessels of mice infected by immersion, but the numbers were small. A mouse, injected subcutaneously with cercariæ obtained from *B. dybowski*, by dissection showed eight adults, of which none were females, when killed thirty-seven days later. In this series, worms were found after the sixth, seventh and eighth week, but the females had not yet begun to lay eggs. On the ninth week, however, the production of eggs had commenced.

Turning to the series of infections by the mouth, the following contrast is interesting: Two Indian monkeys, taken to Egypt from London for the purpose of these experiments, were given infective fluid to drink on the same day. The female monkey received fluid containing cercariæ naturally discharged by *P. boissyi*; that administered to the male monkey contained cercariæ naturally discharged by *Bullinus*. The female monkey began to pass lateral-spined eggs in the fæces on the forty-second day, and died from bilharziasis on the sixtieth day. The male monkey showed no eggs in fæces or urine on the forty-second day and was killed. Many male and female worms were found in the liver and mesenteric vessels, but no eggs were found either free or in the females.

In the worms recovered from these older infections from *Bullinus*, the lateral branches of the gut had now united, and a short cæcum was developing. The males showed a further point of difference from those found in infections by *P. boissyi*, viz., the testes were less numerous, numbering only four to five. As this number had been recorded for *S. hæmatobium*, and was found to occur normally in *B. bovis*, it was still impossible to say whether the *Bullinus* infection was due to the bovine or the human parasite, without the evidence provided by the eggs. A further monkey had meanwhile been infected from *Bullinus* by the mouth. This passed numerous eggs in the twelfth week, and died of intense intestinal bilharziasis five weeks later. No eggs were found in the urine nor were any found in scrapings of the bladder wall. The eggs were terminal-spined without exception and corresponded to those found in man, not those in

cattle. Female worms found post mortem contained the eggs in numbers. This result confirmed the earlier find in mice which had been infected by immersion. Other animals gave confirmatory evidence. We had now established experimentally that the cercaria derived from *P. boissyi* gave rise to lateral-spined eggs, whilst those derived from *Bullinus* gave rise solely to terminal-spined eggs. In both cases infection was restricted to the intestine, but this was probably due to differences in the venous connexions of the bladder. Undoubtedly the gut wall was the primitive habitat of all the bilharzia worms.

The young but sexually mature *B. hæmatobia*, derived from *Bullinus* infection, were well able to lay terminal-spined eggs. Although the very earliest efforts did not conform completely in full size and shape to the standard egg, no evidence of a tendency to the formation of eggs with laterally-distorted spine was forthcoming.

To completely clinch the matter, a final experiment seemed desirable. Animals—monkeys and rats—were infected very lightly with *P. boissyi* cercariæ and kept alive for nine months. The living female worms, found post mortem at the end of that period were still producing lateral-spined eggs; one or two only at a time. For these coupled worms, the "transition period" must surely have long since passed.

The terminal-spined and lateral-spined eggs found in bilharzial infections are, therefore, the normal and characteristic products of two distinct species, *B. hæmatobia* and *B. mansoni*, and are spread by different intermediary hosts. The young females in each species produce slightly atypical eggs, but these slight variations do not "form a continuous series of intermediary stages between the two types."

As transmitter of the parasite of urinary bilharziosis in Egypt, *Bullinus* fulfils all requirements as far as distribution is concerned. It is found in the larger canals, in the smaller irrigation channels and finally, in the village ponds or "birkets." *B. hæmatobia* cercariæ have been found in the species *B. contortus*, *B. dybowski*, and once in a specimen which was recognized as *B. innesi*. These species would appear to correspond to the forms named *Physa alexandrina* by earlier workers.

The more restricted distribution of *Planorbis boissyi* would appear to correspond equally satisfactorily with the less universal occurrence of intestinal bilharziosis due to *B. mansoni* in Egypt. In the course of this inquiry, it was not found in the large canals or in the village "birkets." It appeared to frequent the smaller irrigation channels and drains where these were permanent. It was found also in marshes. Both carriers were found susceptible to drying, *Bullinus* extremely so.

The intermediate host of *B. bovis* remains to be discovered. This parasite was first found by Sonsino at Zagazig, some miles north of El Marg. Several animals were seen infected at the Cairo abattoir, but the majority of these came from the south. The veterinary inspector in charge informed us that *B. bovis* was much more common in Sudanese than in Egyptian cattle.

It may be that the large cercaria occasionally seen in *P. boissyi* at Marg is the infective stage, but of this there is no evidence save that no other Egyptian mammal is known to harbour Bilharzia.

At first it had occurred to me that these differences in size might be accounted for by the separation of the sexes in the bilharzia worms in contrast to the normal state of hermaphroditism prevailing among the Trematodes.

In his postulates Looss had argued in favour of sporocysts giving rise to adults of one sex only, to explain the frequent presence of males only in an infected person. This highly suggestive hypothesis may well prove true for the sporocysts and their resulting cercariæ in the molluscan host.

Experience shows that if the cercariæ discharged from one specimen only be used for experiment, the resulting worms may be of one sex only. Owing to the extreme fragility it was impossible to isolate a single "tube" of cercariæ from an infected liver and so put the matter to experimental proof. Experimentally infected animals, like naturally infected persons, usually show a marked predominance of male over female worms. This would seem to be a happy provision of nature to ensure that no female that had successfully gained her way into the final host should lack opportunity of producing offspring.

OTHER
PROBLEMS. There is one other matter relating to the bilharzia problem as presented by the village Marg which was for a long time puzzling, but for which a tentative explanation may be suggested. Urinary bilharziosis prevailed among the children in Marg to the extent of ninety per cent. The incidence of intestinal and particularly Manson's intestinal bilharziosis could not conveniently be ascertained. The presence there of infection with lateral-spined eggs was revealed by the find of specimens in the urine of one of the infected children. Now in the small canal within the confines of the village, *P. boissyi* was relatively more frequently infected with cercariæ, i.e., with *B. mansoni* than was *Bullinus* with *B. hamatobia*. After many visits the habits of the residents became fairly well known. The shelving banks of the canal served as a public latrine. The sides and uncovered bed of the channel were strewn with fæcal deposits. The Egyptian squatting for the purpose of defæcation faces the bank to observe anyone approaching. Consequently, any urine discharged falls on to the dry surface at a higher level than that at which the stool is deposited. This urine sinks into the dry soil leaving bilharzia eggs on or near the surface where they are exposed to the destructive effect of sun and wind. The eggs passed in the fæces are not so readily killed. It is well known that bilharzia eggs will remain alive and unhatched, in a fairly consistent stool, for weeks under suitable conditions. At Marg the level of the water in the canal rises and falls with a varying periodicity owing to the control in the amount of flow by the irrigation department. The consequence is that the sides of the canal, and especially the flatter portions of the bed, are automatically and

periodically washed. The bulk of the lateral-spined eggs will be set free and will rapidly hatch in the immediate vicinity of the proper intermediary *P. boissyi*. The terminal-spined eggs which hatch are only those that have been passed in the fæces, and to this limited extent the *Bullinus* snails will become infected. Within the village the stream is too shallow for bathing. In the summer the children proceed higher upstream and to the parent canal where *Bullinus* is unaccompanied by *P. boissyi*. It does not necessarily follow, therefore, that the incidence of bilharzial dysentery and hæmaturia due to *B. mansoni* and *B. hæmatobia* respectively should correspond to the incidence of infection in the respective intermediary hosts within the village. Unfiltered water for all uses is taken from this stream into every house in Marg, so that the chances of infection within the home seem very great, both from the use of the water for drinking and for washing. Practically nothing appears to be known of the prevalence of intestinal bilharziosis, especially among women.

BILHARZ'S
"FUNDAMENTAL"
OBSERVATION:
SUGGESTED
EXPLANATION.

Before leaving the Sambon-Looss controversy, I have necessarily to deal with Bilharz's original observation [27], as Looss regarded this find of lateral-spined and terminal-spined eggs in the same female as one of the fundamental facts on which his own view rested.

When first seen by Bilharz the lateral-spined egg was an enigmatical body. It was first thought to be possibly a kind of pupa; only later did Bilharz conclude that it was definitely egg. Bilharz's find of this peculiar body within the female is recorded, as translated by Looss, thus: "such a body was, though once only, but quite undoubtedly, found in the uterus of a female worm, the posterior part of which contained the normal ova."

Sambon contends that Bilharz did not here actually refer to a lateral-spined egg, but to a pigmented body and that "he only says that a peculiar brownish yellow body furnished with a lateral spine was found only once within the oviduct of a female worm, the posterior part of which contained the ordinary ova." There is no clear indication, according to Sambon, that the ordinary ova were terminal-spined ova or that the point of his remarks had reference to the position of the spine, rather than to the dark yellowish discoloration.

To this objection Looss replies later by quoting a further statement by Bilharz: "Strange to say, the eggs appear under two different forms. The two forms were found within the oviduct of the mother as well as in the tissues of various abdominal organs of man."

The latter quotation to my mind brings no support to the contention that Bilharz found the two types within the same individual worm. Here he apparently wishes to convey that the shape of the egg was already determined before the egg left the female and was not a result of distortion in passage through the tissues—a view that has been held later by others.

On the other hand, having read carefully the original text, I am fully

convinced by its context that Bilharz really believed that he had seen the two types in the female, when he wrote the first statement, and that the shape of the egg, not its colour, was what he wished to bring under notice. Earlier in the same paper he describes the normal ova as terminal-spined.

An even more important paragraph in this paper has not been utilized by Dr. Sambon. Bilharz states that this body occurred in one of the first females that he examined. A drawing was made at the time, but no importance was then attached to the observation. A similar condition had not been met with again. Now it seems legitimate to infer that an observation made at the commencement of the research might not have the accuracy or detail of later results when more material was available. The

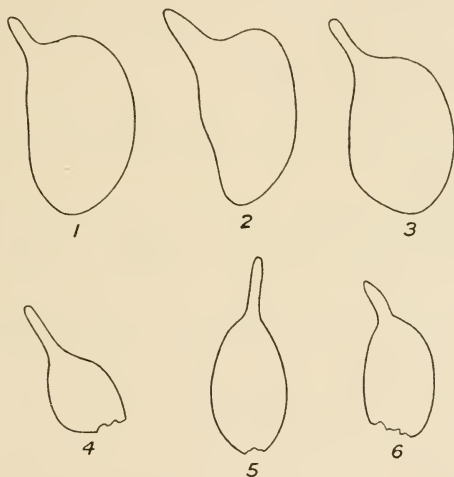


FIG. 86.—A series of eggs (1 to 6) found within the uterus of the same female *Bilharzia*.
(*Journal of Tropical Medicine and Hygiene*, 1911, p. 120.)

eggs with lateral spine are very striking objects, even when seen through the body of the females, but the ordinary ova observed by Bilharz may have been only apparently terminal-spined. My own suggestion is that Bilharz met with one of those females seen occasionally in which egg-laying has only just commenced. I have figured a series of eggs from one such female in the *Journal of Tropical Medicine* for 1911 [271]. The outlines are reproduced here. The first-formed egg (1) is lateral-spined, and lay just within the vulvar opening. The others (2 to 6) lay one behind the other towards the ootype, (6) having just passed from the ootype. All the eggs were rolled to show the greatest amount of lateral displacement of the spine. The later samples, it will be noticed, were incomplete and did not contain an ovum. These were, in fact, casts of the ootype in egg-shell

without normal content. If Bilharz met with a female similar to this one at the commencement of his investigations, he might well have concluded that the worm contained both types of egg.

When these sketches were made, I thought they might give support to the view put forward by Ward that the terminal-spined type of worm produced at first abnormal eggs with a sort of lateral spine; not identical with the lateral-spined egg of the New World.

On this interpretation the female was actually in Looss' "transition period," but the formation of standard terminal-spined eggs had not been reached. I now believe that the female was one just commencing to lay; that ovulation had not fully set in; and that after producing one or two complete eggs a number of casts of the ootype in egg-shell were thrown off. I have since met with similar abnormal lateral-spined eggs in the material obtained by maceration of the liver of animals experimentally infected with *S. mansoni* in Egypt.

OTHER MODES
OF INFECTION. Among South African tribes there is a widespread belief that the cause of hæmaturia there, which we know to be bilharzia, enters the body through the orifice of the penis during bathing.

To prevent this certain races, such as Zulus, wear a basket-like protection. Pfister [323] has shown that a similar belief and a like form of protection prevailed among the ancient Egyptians. Its mode of use is to this day figured on the walls of some of the ancient temples of Egypt.

The belief, so far as I am aware, is no longer current among the native populace in Egypt. It has however spread in South Africa among the white population although the protective measures do not seem to be in vogue with them. The matter is of interest here because, as I am told, troops proceeding to Egypt were instructed that they could avoid bilharzia infection while bathing in the canals there, if they took the precaution of wearing the European equivalent of this ancient speciality.

During the field work in Egypt certain observations seemed to afford a rational basis for this ancient belief. Often one found small and very agile leeches on the nets and collecting gear. These were indeed a great pest, for unless they were carefully excluded from the aquaria they rapidly destroyed the molluscs. Now I have heard of one or two cases where such a small leech entered the penis during bathing, and, lodging in the urethra, gave rise to profuse bleeding. This I believe is the probable origin of the association of a penile ingress with bilharzial hæmaturia and in so far as these penile sheaths have proved efficacious this is probably due to the exclusion of leeches.

In this report it has been shown that infection through the mouth is readily induced experimentally. As the acidity of the stomach destroys the cercariæ, it has since been argued that such experiments are of little practical significance, giving merely an extension of the area of skin infection. I am personally inclined to attach much more importance to this

demonstration of mucous membrane invasion; more especially as it brings me into line with the conclusions of Day. This distinguished observer came to the conclusion from a close study of the conditions of infection in Egypt that the nasal and oral ablutions, carried out as a part of religious ceremony, played no small part in the repeated infections with bilharzia seen in the Egyptians, more especially of male sex. One of the most heavily infected sites in Marg was at the water's edge immediately in front of the local praying ground upstream of the village.

From the established facts regarding the mode of spread and of infection it is evident that troops deriving their water supply for all purposes from the large public water-works run no risk of infection, even though the washing places become accidentally contaminated with urine containing bilharzia eggs. The risks were among those stationed in small parties on the various bridges, roads and canal crossings throughout the Delta and among the troops occupying new camps on the freshwater canal, in the Fayum and elsewhere. Although supplied with pure water for drinking purposes, this had often necessarily to be supplemented by local supplies for general purposes. At one such place it was pointed out to me that the daily ration of water could be supplemented with ease "from a wee bit burn" which seemed to be of clear good water. A brief examination showed however that there were many *Bullinus* in this stream, which was simply an irrigation channel derived from a main canal on which was a large native population a mile or two inland.

Asked on one occasion what I thought were the risks from uncontrolled access to canals in the neighbourhood of camps during the summer I put down a conservative estimate of ten per cent. It is therefore of interest, and indicative of the value of the propaganda and prophylactic measures afterwards undertaken, that in two squadrons stationed at one of these camps during the summer of 1915 no less than twenty-seven, i.e., about twelve per cent strength contracted bilharziosis.

With the information at the disposal of the troops bilharziosis should now be treated as one of those diseases for which the individual is mainly, if not entirely, personally responsible.

MORPHOLOGICAL DIFFERENCES BETWEEN THE TWO EGYPTIAN SPECIES.

After the publication of *B. mansoni* as a distinct species in 1911, several American workers made a study of the anatomy of adult worms collected in the West Indies, Panama and Brazil, in search for morphological characters by which the species with lateral-spined egg could be distinguished from the terminal-spined form found in the Old World.

Comparing their finds with the formal descriptions given by Looss and others, they noted and briefly described the following peculiarities.

Holcomb [233] found that the adults of *B. mansoni* had a brown colour and a somewhat larger ventral sucker. Piraja da Silva [444] was struck by

the unusual appearance of the anterior end of the male worm which differed in outline from that figured, after Looss, as characteristic of the Egyptian worm in most text-books. The female appeared to taper towards the posterior extremity instead of ending abruptly. The cæcum approached the end of the body more closely. The oviduct united immediately with the vitelline duct instead of passing forwards to fuse with it at the ootype. The spinous papillæ did not seem so salient.

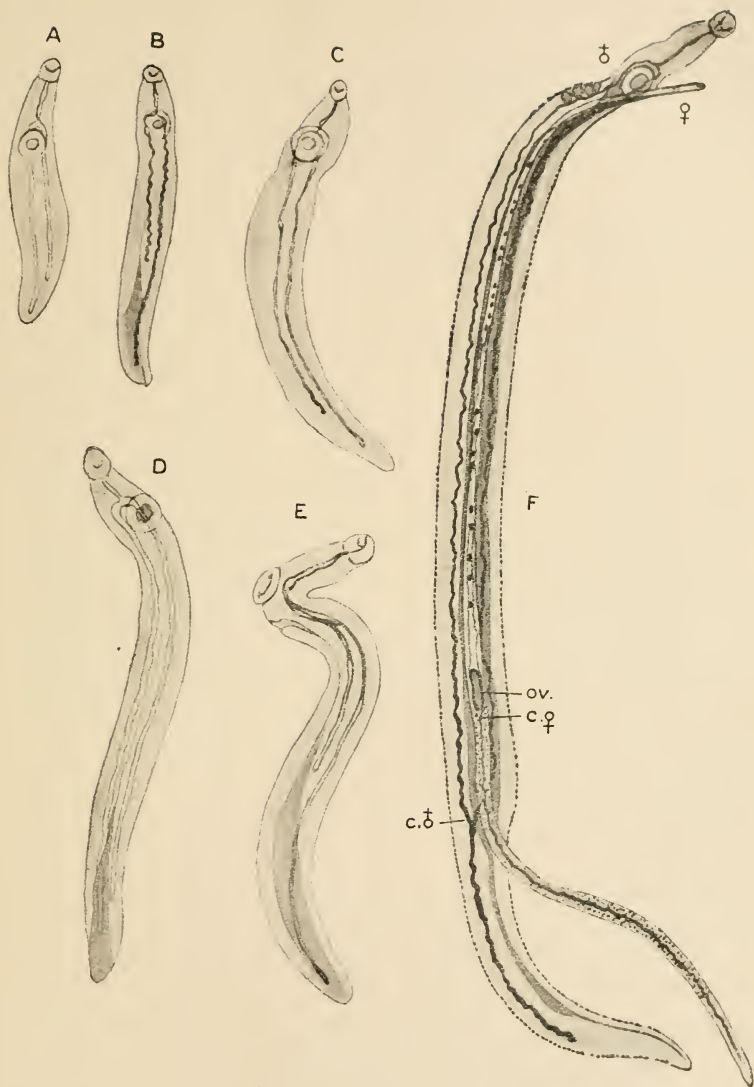
Flu [172] saw differences in the manner in which the anterior edges of the lateral walls of the gynæcophoric canal joined the body in the male and in the female in the presence of a coiled ovary in full-grown specimens.

A further point of apparent differential importance was noted by myself in 1908 as a result of an examination of a batch of male bilharzia worms, collected at post-mortem by the late Dr. Turner, from cases of mixed infections in natives of Portuguese East Africa and Nyasaland. I quote the following interesting portion from my half-yearly report to the Colonial Office in May, 1908. "In cases of mixed infections (as ascertained by microscopical examination of bladder and rectal walls) I have been able to separate into two groups males having four somewhat angular large testes and males having seven to nine small spherical testes. In other cases all the males obtained belonged to one type. The difference in character and especially in number of testes would be considered as a specific character of some reliability if occurring in other groups and if constant as it seems to be here. In order that this character can be utilized in support of the view that the two forms of bilharziosis, rectal and urinary, are caused by parasites specifically distinct, it remains to be shown that males having one particular type of testes are usually or always in sexual conjunction with females producing one type of egg.

"Granted for the moment that these types of testes and of egg be found to occur constantly, the probabilities are that the male with four testes is the mate of the female giving rise to terminal-spined egg; for this is the normal arrangement of testes figured by Looss and the terminal-spined ovum is the one recognized by him as the normal product of the mate of this form.

"In support of this view, I am able at present to offer only one actual observation, in itself a striking one, owing to the lack of females in my material. In the one specimen of a paired couple in my possession, the testes can easily be made out to be seven. The female lies in the gynæcophoric canal, but its posterior half is broken off. Lying also in the canal, however, is a small 'clot' containing several lateral-spined ova. We have, then, evidence of the association of the multitesticular male with the female having lateral-spined eggs."

Replying to the points of difference as set out by Piraja da Silva, Flu, etc., Looss [300] maintained that these features were to be seen equally in specimens of *B. hamatobia* in Egypt, and that they might be explained at least in part by varying degrees of contraction in the preserved worms.



FIGS. 87-92.—*Bilharzia hamatobia* (s. str.), developed from cercariae discharged by *Bullinus* spp.

A—E = Immature stages from liver showing delayed union of gut.

F = Adults in copula from mesenteric vein, showing short caecum and corresponding changes.

ov. = Ovary.

c. = Commencement of caecum.

As the chief monographs on the anatomy of the adult bilharzia worms were based on materials collected in Egypt, such material quite probably came from mixed infections. A comparison of the anatomy of adults of *B. mansoni* from uncomplicated cases in the New World with these published descriptions of *B. hamatobia* was not likely to lead to acceptable conclusions.

It is evident then that a final settlement of the specific differences between the adult worms of *B. hamatobia* and *B. mansoni* must be based upon a comparison of specimens taken from cases of unmixed infection and preferably from cases in South Africa and the West Indies respectively, where such infections occur.

The bilharzia worms that have been reared experimentally from *Bullinus* and *Planorbis*, unfortunately, do not attain in the laboratory animals the full growth met with in their natural hosts. Although sexually mature and actually producing eggs, the worms are still young and small. Differential characters based upon measurements are likely to be fallacious under these circumstances. Morphological differences, may, however, be relied on; especially where these can be verified by reference to full grown adults taken from the human body in unmixed cases of vesical and intestinal bilharziosis. Unfortunately, an opportunity of obtaining such material has not been forthcoming hitherto. The following account of the differential characters as seen in experimentally reared worms must be regarded as a purely tentative attempt to differentiate the two species. It will be noticed, however, that it gains some extraneous support in the observations on the anatomy of *B. mansoni* quoted above.

In the males reared from *Bullinus*, the testes appear to number four or five almost constantly. They are also of fairly large size.

In males reared from *Planorbis*, the testes number seven to nine, and appear to be relatively small. Differences between the two sets of males are noticeable in the shape of the anterior portion bearing the suckers, and the relative size of the suckers is probably also to be regarded as of specific account.

In females reared from *Bullinus*, the eggs are constantly terminal-spined, even in small young females. The ovary is smooth and situated near the middle of the body. The lateral branches of the gut are lengthy and the cæcum correspondingly short. With this the range of the yolk glands which surround the cæcum throughout its length is apparently short.

In females reared from *Planorbis boissyi* the eggs are constantly lateral-spined. Usually one, seldom two, and very rarely, four eggs, occur in the uterus at one time. This is due to the short length of the duct. The lateral branches of the gut unite early, and there is a very long cæcum. The yolk glands surrounding the cæcum have, therefore, a correspondingly long range. The ovary lying in the fork made by the union of the gut branches is elongated and is within a short distance of the uterine pore.

The difference in the point of union of the lateral branches of the gut in the two species is common to male and female. It is a very noticeable feature in the growing worms. The posterior portion of the young worm would seem to be a growing tissue, which, by its continued lengthening, changes the relative measurements of the various parts of the gut almost until maturity is attained.

The attainment of egg-production is more rapid in *B. mansoni* than in *B. hæmatobia*. In experimental infections from *P. boissyi* eggs were found after six to eight weeks, from *Bullinus* after nine to twelve weeks, depending on the intensity of infection and on the host.

The developing worms and coupled adults reared from *Bullinus* infections are illustrated in figure on p. 129.

The question of nomenclature remains now to be NOMENCLATURE. reconsidered in the light of the foregoing results. The generic name Bilharzia, proposed first by Cobbold [92], gained almost universal acceptance, especially in medical works and in contributions on the clinical and pathological aspects of infection. I have used the name Bilharzia in the present report, as it is the one by which the disease is commonly diagnosed. Within recent years, however, the name Schistosoma, given by Weinland [515], in 1858, has been revived under the present operation of the Laws of Nomenclature. It is the more correct, although Cobbold states that under the laws in use at the time, Weinland accepted the priority of Bilharzia over Schistosoma. If the former generic term is used, the species should read, *Bilharzia hæmatobia*, and if the latter *Schistosoma hæmatobium*. It is to be hoped that on grounds of use and suitability, the specific names of *Bilharzia hæmatobia* and *Bilharzia mansoni* may retain their present application. Doubtless some day, it will, however, be noticed that the *Distomum hæmatobium* originally named by Bilharz, was based upon mixed material, and is, therefore, a composite species. Harley, the first reviser of the species, split this *D. hæmatobium* into two components. To the species giving solely terminal-spined eggs, he gave the name *D. capense*, restricting the name *D. hæmatobium* to that form found in Egypt which produced both kinds of eggs. I foresee that the name *B. hæmatobia* may thus be reserved by purists in nomenclature to the single specimen described by Bilharz, which conforms with these requirements.

There finally remains the *Bilharzia magna* found by Cobbold in a monkey. The type and only specimen, is preserved in the Hunterian Museum. It is a fragment of a male. I have been quite unable to identify it with either of the species now recognized in man. This is a happy circumstance, for we may now without anxiety retain the specific name of *B. mansoni* (with which the whole species problem has been indissolubly connected), in its rightful place to recall for future students the insight of one who took no part in controversy, but silently worked through others less inspired, for the eradication of many of the great pests of the Tropics.

PART VI.
PREVIOUS WORK ON *B. JAPONICA*
AND
CONCLUDING REMARKS.

BEARING OF PREVIOUS WORK ON *B. JAPONICA* AND CONCLUDING
REMARKS.

GIVEN the premises laid down by Looss as a result of prolonged study of local conditions in Egypt, his theory, "based upon a large number of anatomo-pathological and helminthological facts deliberately weighed and compared," could not be overthrown simply by an argument from analogy. If it were otherwise, those who accepted and supported his views bear a heavy responsibility for failing to apply the analogies resulting from the experimental data afforded by experiments with *B. japonica*; the first and most fundamental of which, made by Fujinami and Nakamura in 1908, excluded, for this allied species, the possibility of direct transmission.

In the opening section of this report, I have traced the evolution of scientific opinion regarding the mode of spread of *Bilharzia hæmatobia*. The analogies presented by *B. japonica* have there been referred to only to show how these were definitely set aside by the exponents of the theory of direct infection in Egypt. I have refrained from using them as an a priori argument, because in the proved facts of the life cycle of another common Egyptian parasite of man there was a strong opposing analogy, in support of the possibility of an exceptional occurrence of direct infection among parasites requiring usually an intermediate host. *Hymenolepis nana* has been shown experimentally to be capable of direct transmission although the other members of the genus have arthropod intermediaries.

Moreover, the object of my own work has been to arrive at a solution of the various problems, presented by the bilharzial diseases in Egypt, by direct observation and experiment, rather than by the inductive method.

I propose to relate now the various published facts concerning the life-history of *B. japonica* that were available at the outbreak of war; to show in what respects these failed to afford the data necessary for a rapid solution of the bilharzia problem in Egypt and in what way my own investigations on this Oriental species, while confirming previous conclusions of Japanese observers, gave a new method by which the infective

stage could be quickly and accurately delimited in the molluscs of a heavily infected locality. By its use the peculiar difficulties which have so long beset the bilharzia problem in Egypt were speedily overcome.

Before dealing with these investigations, I must recall that the problem of the bilharzia worms was not one of a peculiar and new type of larval development. It concerned rather the seat of this development and the exact route by which reinfection of man took place.

Holdings of the theory of direct transmission were in agreement with their opponents that the larval metamorphosis of the bilharzia worms conformed, in all essentials, to that of other digenetic trematodes. Thus Looss, in 1908, wrote: "The existence of these (germinal) cells in the bilharzia miracidium is absolute evidence that the miracidium cannot develop directly into an adult worm, but must pass through the stage of the sporocyst which in its turn produces, either and probably at once, or by one or more intermediate generations, the definite worms."

The fundamental problems for each species of bilharzia worm were these: (1) Did the species follow its typical larval development in the liver of man or of a mollusc? (2) Did infection take place through the skin or by the mouth? (3) If a mollusc was an essential intermediary, what were the species concerned in the transmission of each species of worm? As regards the *B. japonica*, the first and second of these problems were, to my mind, conclusively settled by the researches of Fujinami and Nakamura in 1908.

In those regions in the Far East where man is infected with *B. japonica*, infections also occur naturally in cattle, cats and dogs. Using these animals therefore, as tests and controls, the following experiments were made. In the first investigation numerous miracidia were hatched in water. Dogs were then immersed in this. No results followed. In the second series, cattle, cats and dogs were submitted to possible infection by immersion in rice-fields and neighbouring ditches and streams reputed to be sources of infection. Intense infections with *B. japonica* ensued.

In 1910 other animals, not found naturally infected, were proved susceptible by experimental immersion, viz., mice, white rats, guinea-pigs, rabbits and monkeys.

In these experiments, described by Fujinami in a paper issued from the Internationale Hygiene Ausstellung in Dresden, in 1911, young parasites only 0.15 millimetre long were found in the portal system on the third day after immersion.

In 1911 Miyagawa described the invasion forms, as seen in the peripheral vessels and cutaneous tissues in two to twenty-four hours after immersion. These forms were smaller than those seen by Fujinami but differed in no essential respect. Oral and ventral suckers and a gut were already present.

In 1913 Miyairi, by experimentally infecting local molluscs with miracidia, found a sporocyst in an unidentified snail, stated to be a

Lynnæus, as Katsurada announced in a footnote to an article on "Schistosomiasis japonica," in December (*C. f. Bkt.*, 72, p. 378). Miyairi's original publication is in Japanese, but Kunagawa gave a summary of the chief points in an abstract published in the *Tropical Diseases Bulletin*,¹ in March, 1914.

"They noticed also that in the infested locality there are many snails in the waterways and ditches. Of these snails a great many Cercariae parasitize one which has a dark-coloured shell with seven spirals. The authors carefully picked up a number of young non-infected snails and tried whether the miracidia entered their bodies or not. They found that the miracidium enters the body of the snail, penetrating the cuticle with the lips and proceeds to the gills and the wall of the digestive canal. After twelve days the first rediæ appear and gradually concentrate to the hepatic ducts, elongating, and a number of the second rediæ are seen. The authors put mice into the vessel in which the full-grown snails were fed, for three hours every day and repeated this experiment for four days. After three weeks they found a great many *Schistosoma japonicum* in the livers of the mice. The authors conclude that this kind of snail is an intermediate host of *S. japonicum*."

Judging by titles, other papers appeared in Japanese journals, but these are inaccessible. During 1914, Katsurada (according to an Italian abstract) "confirms the assertion of Miyairi and Sudzuki, but regards the question of the intermediate host of *S. japonicum* as not altogether cleared up."

It is evident that the above information, while definitely establishing a molluscan intermediary for *B. japonica*, was of little value as a guide to the elucidation of the special problems surrounding the *B. hæmatobia* transmission, and gave no facts regarding the bionomics of the infective stage, or of the carrier, upon which to base prophylactic measures. In Egypt all attempts to advance by infecting with the miracidia had failed, even in Looss' skilled hands. Sonsino and others had found no means of identifying the *B. cercariae* among the numerous developmental stages found in the snails of the endemic area in Egypt. There was not available for experimental purposes any animal of known susceptibility but man. Lastly, there still remained no explanation of the frequency of bilharziosis amongst very young children in Cairo.

In an article published in Mense's *Handbuch* in 1914, Looss admitted when dealing with *B. japonica*, that after Miyagawa's experiments the existence in this species of a free swimming cercaria was quite plausible. Under *B. hæmatobia*, however, he states that if it is correct that there is an intermediate host in the Oriental species, "then *B. japonica* must differ essentially in its development from *B. hæmatobia*." That Looss' view was still maintained by others is shown by the advice tendered to the

¹ Full titles and abstracts of the preceding and of all available publications on *B. japonica* are to be found in the volumes of the *Tropical Diseases Bulletin*.

Army in Egypt for dealing with an outbreak of bilharziosis amongst the troops stationed at Kasr Nil Barracks during 1912. In an article in 1915 by another authority in Egypt the following occurs: "Any small puddle or hole may become defiled, and in a very short time the water or mud is alive with miracidia, which may become applied to the bare feet, arms or hands, penetrate the skin directly and so lead to infection." "Certain evidence we have none nor has any intermediate host ever been discovered."

Reviewing the bilharzia problem in the Spring of 1912, in the light of Fujinami's experiments and the repeated failures to infect monkeys and other animals with the miracidia of *B. hamatobia*, I concluded that the time had come to renew the attempt made by earlier workers to establish a molluscan transmission for this parasite.

In view, however, of the lack of success which had attended the previous efforts of Sonsino, Lortet and Vailleton, and others to follow the miracidia, a new method of approach seemed called for.

The occurrence of *Bilharzia magna* in *Cercocobus fuliginosus* rendered it not improbable that by subjecting monkeys of this species to immersion in water containing the various cercariæ, found in the endemic area, a positive result might eventuate. As *B. hamatobia* occupied a peculiar habitat in man and did not naturally infect any other animals a negative result might follow. In any case such an empirical method would obviously involve the purchase, transport and maintenance of a large number of monkeys or necessitate an unusually prolonged investigation, for which the necessary financial support was not likely to be forthcoming.

The experiments of Fujinami and Miyagawa appeared to me to open up a possibility that a morphological clue might be established by which the bulk of cercariæ of unknown origin could be excluded microscopically; thus bringing the experimental use of monkeys within practical limits.

Was there any outstanding feature which distinguished the adult distomes from the adult bilharzia worms and which had, in all likelihood, persisted from the sexless cercarial stage? In the cercaria there are organs, like the tail, which are purely larval structures, and others, like the suckers and the gut, which persist from the body of the cercaria through adult life. In some cercariæ, however, the gut has not yet formed although there is an oral sucker.

The suckers are, both as regards structure and position, very similar in distomes and bilharzias. The alimentary canal is, on the other hand, markedly different. The bulk of the distomes have a separate muscular pharynx. There is no pharynx in the bilharzia worms.

If this distinction were one which persisted from the cercarial stage then it afforded an easily determined morphological clue by which one could immediately exclude the vast majority of cercariæ, which are distomes.

It might be that the pharynx, originally separate, became fused with

the oral sucker in the adult as occurs in the amphistomes. Without definite evidence it was, therefore, impossible to come to a trustworthy conclusion regarding the absence of a pharynx in the cercaria of bilharzia.

Happily such evidence was now procurable as a result of the discovery of the "invasion forms" of *B. japonica* by Fujinami and Miyagawa. From the description of these bodies, which were said to possess oral and ventral suckers and a developed gut, it was evident that they were infecting cercariæ, but there was no mention, in either paper, of the presence or absence of a pharynx.

It was obviously necessary to establish this point by actual observation, not merely by inference, if it was to be utilized as a basis for experimental work.

My plan then was, in 1912, to proceed to Japan, and by repeating the original experiments or by examining the original preparations to settle this question; to confirm the expected value of the clue by examining the molluscs of the district where Fujinami has conducted his immersions and which was known to be intensely infected; and thence to proceed to Africa. If one or more of the molluscs there was found to contain cercariæ exhibiting this peculiarity, then it would be possible to attempt the experimental transmission of bilharzia to monkeys with every prospect of success.

These plans were, however, subject to other counsels and it was not until the summer of 1914 that I felt free to carry out my original scheme. This I was then enabled to do fully, thanks to the cordial co-operation of Professor Fujinami. Through him I was able to examine the "invasion forms" and to establish the value of my morphological clue by a visit to the rice fields of Katayama, where the ease with which the test could be applied to the molluscs in an endemic area was quickly demonstrated. With cercariæ exhibiting this morphological peculiarity, mice were afterwards infected successfully with *B. japonica*.

In the meantime, however, Miyairi and Sudzuki, as related above, had succeeded by another method of approach in tracing the metamorphosis in a closely allied, if not identical, snail, in the South Island of Japan. My own observations therefore confirmed generally the results of these workers, apart from establishing my chief, ulterior object; which was to provide a simple and reliable means of attacking the complex problems of *B. hæmatobia*.

In regard to details, concerning which only the abstract by Kumagawa was available, I was unable to confirm the presence of "redia" in the development of *B. japonica*. From my own observations I had concluded that the *B. cercariæ* originate in sporocysts. I was not in a position, pending fuller information, to decide whether these "redia" were actually developmental stages of bilharzia or of some other species with which the

snails, experimentally infected with miracidia, had been naturally infected previously.¹

On my return voyage, after the outbreak of war, I visited Egypt and found that though the results of the recent work on *B. japonica* were known there, it was still held that they gave no solution to the special problems presented by the *B. hamatobia*.

Considering that the new facts derived from my own observations on *B. japonica* would enable me to overcome the experimental difficulties which had hitherto surrounded the Egyptian question and realizing the immediate importance of some simple and efficient prophylactic measures for the large bodies of troops then proceeding to Egypt, I sought and obtained the occasion for the investigations in Egypt related in this report. A study of the accounts given by Sonsino and Looss of the cercariæ found by them in the course of their search showed that they had not seen and passed over the *B. cercariæ*. The bulk of their cercariæ possessed a distinct pharynx. In a few it was absent but in these there was merely an oral sucker without any development of œsophagus or gut. It was evident that these forms had still to undergo maturation before they could become infective to their definitive hosts and as some possessed a definite perforating spine and other peculiarities of forms that undergo encystment in fishes and other secondary hosts, these cercariæ were readily excluded. It was therefore necessary to find further cercariæ which had hitherto been overlooked. The search for this was made by the method of intensive study of a small heavily infected area. The fact that *B. japonica* developed in a genus of the family hydrobiidæ was of no assistance. Indeed by those unversed in the bionomics of helminths this might have been taken, disastrously, as an additional and invaluable analogy. In point of fact the Egyptian bilharzia worms were found to infest two genera of freshwater mollusca belonging not merely to a different family but to a different order. In other words, *B. japonica* and *B. hamatobia* (s. lat.) were found in snails as distantly related in classification as are the lice to the mosquitoes. In

¹ In Egypt we found commonly present in the species which were actually intermediaries for the various *Bilharzia cercariæ* additional developmental forms; some developing in rediæ and other, bifid-tailed, forms developing in sporocysts which bore a superficial resemblance to *B. cercariæ*. It is obvious from the illustrations given by Cawston that such forms were mistaken by him for *B. cercariæ*. Thus, prior infections may prove a serious source of fallacy to those endeavouring to advance experimentally from the miracidia unless the results are carefully checked by the morphological method.

In a report written on my return from China in October, 1914, I had to content myself with the statement that my results confirmed Miyairi's main conclusion, and that in the absence of any accessible publications a comparison of the detailed conclusions was for the present impossible. Apparently during the closing months of 1914, Miyairi and Suzuki published in Japan, in German text, a detailed account of their findings. From this, which is well illustrated, it is now evident that divergence of view regarding these "rediæ" is due solely to a difference in interpreting the same structures.

its application to these new cercariæ the morphological clue fully vindicated its use. Within three months no less than four *B. cercariæ* were obtained by this method of exclusion. Two of these were selected, on epidemiological and other grounds, and with these two alone experiments were made on *Cercocebus fuliginosus* and other animals. These forms proved to be the infective stages of the two bilharzia worms which cause bilharziosis in man in Egypt. No experiments were made with any other cercariæ.

Here I may well bring to an end a Report that has been kept open much longer than was intended, and of which the earlier sections were written while experiments were yet in progress. Much material remains which, when elucidated, should add further to our knowledge of these and allied Egyptian parasites. Its description, however, scarcely comes within the terms of the present inquiry, which were "to investigate bilharzia disease in Egypt, and advise as to the preventive measures to be adopted in connexion with the troops." These objectives, I believe, have been fully achieved. A complete zoological study of the adult parasites, or of their development, has not been attempted. Such attention as has been given to their morphology and bionomics has been directed to those points concerning which an understanding was essential as a basis for prophylactic measures. The difficulties which beset the inception of the work in a strange country, with some elements critical and hostile, were quickly overcome. Sickness, however, almost wrecked the inquiry at its commencement. Within a month of our arrival Dr. Cockin had fallen sick, and was invalided home. Three weeks earlier I had been admitted to hospital with scarlet fever. It was not until the beginning of April that, foregoing my convalescence, I was able to start field investigations at Marg. Early in May the opening of the Gallipoli campaign, with its rush of wounded and the attendant excitement in Cairo, brought pressing local suggestions for the foreclosing of my mission. As on some other occasions, one found comfort in the aphorism of Huxley: "Surely there is a time to submit to guidance, and a time to take one's own way at all hazards."

But the pervading restlessness could not be wholly withstood. Later, in June, when it seemed advisable to transfer the work to London, my second colleague, whose assistance had been invaluable, decided to remain in Egypt for general service with the Royal Army Medical Corps. The position of the inquiry was full of anxious uncertainties, and I had still to complete many of the crucial experiments. The collections made in the field had still to be worked out, and the experimentally infected animals examined histologically. The extensive literature of Bilharziosis had to be overhauled. Finally, new experiments had to be made. These were the circumstances in which the preparation of the Report had to be undertaken, and sole responsibility assumed for the conclusions arrived at and for the views herein set forth.

APPENDIX.

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viii *Report of the Bilharzia Mission in Egypt, 1915*

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xvi *Report of the Bilharzia Mission in Egypt, 1915*

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xviii *Report of the Bilharzia Mission in Egypt, 1915*

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